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This report is the summary report of a study of 14 urban areas to determine the reasons for attainment or nonattainment of the National Ambient Air Quality Standards. This summary report combines the data from the particle characterization and urban area reports to provide a national assessment of the problem.

The report evaluates three major factors affecting attainment - (1) large scale effects from transported primary and secondary particulates, (2) traditional sources such as fuel combustion, industrial process and solid waste and (3) nontraditional sources such as mobile source exhaust, tire rubber, construction, paved and unpaved roads, etc. Two factors which modify measured levels, meteorology and monitor siting, are also evaluated.

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VOLUME I

SUMMARY OF NATIONAL ASSESSMENT

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EXECUTIVE SUMMARY

This report presents the results of a study conducted to assess the national particulate problem in urban areas, with emphasis on identifying the factors involved in the attainment or nonattainment of the National Ambient Air Quality Standards (NAAQS) for total suspended particulates (TSP), and to develop recommendations for future action and research needs.

The overall approach to the study involved a series of case studies in 14 major urban areas, including a field visit to each area to conduct detailed inspections of the TSP monitoring sites. No major field measurement programs were undertaken, but selected hi-vol filters from the case study cities were analyzed by microscopic techniques to provide information on the types and sources of the particles collected. Some of the filters were also analyzed by EPA for metals and nonmetallic inorganic ions.

Although this study approached the national particulate problem with many of the same tools an individual air quality planner would use to assess the problem in a particular urban area (air quality data analysis, emissions data analysis and modeling, and analytical particle identification), the intent of the study was to provide comparable data for extrapolation to the national scale rather than a detailed study of each urban area. Though the results and conclusions of this study are primarily applicable on a national scale, the technical information can be useful to local air quality planners through comparisons of the more general data to the specific problems in their urban areas.

GENERAL FINDINGS

Factors Affecting Attainment

The study grouped the various factors that affect attainment and maintenance of the TSP standards into five conceptual categories as follows: three general categories of sources that contribute to the TSP loading at any given point, and two factors that act to modify the ambient levels measured. The three general categories are emissions from traditional sources, emissions from nontraditional sources, and natural and transported particulates. The two modifying factors are meteorology and monitoring network configuration and siting.

Traditional sources are those sources that have historically been of concern to the air pollution control community. Fuel combustion sources, solid waste disposal operations, and industrial process emissions, including both stack and fugitive emissions, comprise this segment. Particulate emissions from traditional sources were found to have decreased significantly in most areas since the State Implementation Plans (SIPs) were applied, with resulting improvement in TSP air quality. However, these sources are still the dominant problem in some urban areas with much heavy industry; in these cities, traditional sources may be contributing anywhere from 15 $\mu g/m^3$ in residential areas to over 60 $\mu g/m^3$ in industrial neighborhoods. These levels can be reduced significantly if sources are brought into compliance with stringent regulations. The traditional sources that remain the greatest problem are the primary metals and mineral products industries, as well as fugitive emissions from all traditional sources. While the stack emissions are usually controlled through standard regulations, the control of fugitive emissions requires new regulations such as those which control operating practices or concentrations crossing the boundary line.

Nontraditional sources include reentrainment of road dust, fugitive dust emissions from construction and demolition operations, particulate auto exhaust emissions, dust from unpaved areas, and emissions from other urban activities. These sources have not been controlled adequately under existing SIPs, and in many cases were not even considered. A principal finding of the study was that particulates from these sources contribute 25 to 35 $\mu g/m^3$ to the citywide TSP levels, thereby preventing many urban areas from attaining the ambient standards; unless controlled in the future, they will continue to do so. The control measures that must be applied are also nontraditional: controlling dust deposition or cleaning streets to reduce reentrainment from paved roads; chemical stabilization, cover, or other means of lowering surface disruption at construction/demolition sites or on unpaved areas; reducing lead in gasoline or requiring particulate control devices for motor vehicles.

Natural and transported particulates consist of those contributions to the large-scale TSP level frequently called "background." The long-range transport of both primary and secondary particulates, as well as naturally occurring particulates, are included in this portion. Normally, the different contributions to these particulate levels have not been considered in air quality planning, although their reduction may be essential for standards attainment. While natural particulates are not amenable to control, the nonurban levels of sulfates and nitrates (in the range of 5 to 10 $\mu g/m^3$ in the northeast) and transported primary particulates (up to 30 $\mu g/m^3$ in dense metropolitan areas) can be controlled through regional planning. In addition, the portion of urban secondary particulates (as much as 10 $\mu g/m^3$) that is formed from gaseous emissions within the urban area should be considered in regulatory programs.

Meteorological factors were analyzed to determine the extent of their effect on the magnitude of ambient particulate levels. For example, precipitation was found to change annual average TSP levels as much as 20 $\mu g/m^3$ over the normal range of precipitation values. The location of the area with respect to movement of air masses from other regions can affect the nonurban levels coming into the area; the number of heating degree days, along with the fuel available for heating, can also affect the TSP levels. Although not a factor subject to control, the variations in meteorological effects over time and in different locations must be considered in air quality management planning. The results of this study's analyses will help in doing this more quantitatively.

Network configuration and hi-vol siting affect the perception of particulate levels. Variations in siting practice and network configuration make comparisons of values between cities and neighborhoods difficult. These variations frequently distort the overall picture and constrain problem identification and subsequent strategy development which is essential for attainment/maintenance. Often, differences in the monitor's location of only 100 meters on the horizontal or 15 meters on the vertical can change the measured TSP levels as much as 50 $\mu g/m^3$. Nevertheless, such variations in monitor siting are within the general guidelines prescribed by EPA.

SPECIFIC FINDINGS

Underlying the general conclusions outlined above are a variety of specific findings in the areas investigated. The evidence developed and findings reached are described below.

Microscopic Analysis of Filters

In the course of the study, 300 hi-vol filters from the 14 study cities were examined by polarizing microscope to determine the mass percent contribution of the major generic categories of particles. The average mineral content of the particulates was found to be 65 percent of the mass, while combustion products averaged 25 percent. The cities with the highest percentage of minerals were Denver and Oklahoma City, both areas of dry climate with acknowledged fugitive dust problems. Both of these cities averaged over 80 percent minerals, with most reported as quartz and calcite. In only two cities, Cincinnati and Cleveland, did the contribution from combustion products exceed 40 percent. Biological material was not a major component on the average, though some filters collected in the spring showed as much as 90 percent biologicals. The contribution of rubber was also highly variable, ranging from 16 percent in San Francisco to 2 percent in Philadelphia and Washington, and averaging 7 percent.

Aside from the particle identification, valuable information was also collected on the technique of microscopy as a routine analytical method by using two laboratories, multiple analysts, and blind replicate examination of filters. The comparison of different analyses of the same filter indicates that some very sizable differences can occur between analysts; statistical analysis of the results of the blind replicate examination of samples warns against relying heavily on any single result. However, composited results can be used to point out important differences in the composition of suspended particulate matter as a function of time and location.

Traditional Source Emission Density

By comparing the density of emissions from traditional sources (fuel combustion, industrial processes, solid waste incineration) and the citywide TSP levels, it was possible to develop a relationship for estimating the impact of increases or decreases in the emission density. While the actual impact will vary with the completeness of the emission inventory, the meteorological and climatological factors, and the topography of the area, a rule of thumb is that the citywide TSP level will decrease approximately 8 $\mu g/m^3$ for every 100 tons/year/square mile decrease in the emission inventory.

This same analysis indicated that even the cleanest cities (with respect to traditional sources) will be 30 to 40 $\mu g/m^3$ above the local nonurban levels due to nontraditional sources. Therefore, all cities of the size considered in this study can be expected to have at least one site exceeding the secondary annual standard. Cities with traditional source emission densities greater than 100 to 200 tons/year/square mile will need further control of traditional sources to be able to meet the primary annual standard.

Fuel Combustion Emissions

In the 14 cities studied, the fuel combustion contribution to inventoried emissions ranged from less than 20 percent in clean-fuel, industrialized areas to well over 90 percent in totally nonindustrial areas. The total emissions due to fuel combustion vary with the type of fuel available, the degree of industrialization, population, and heating degree days. In cities where fuel oil was the predominant energy sources (used in more than one third of the residences), filters selected for microscopic analysis contained from 9 to 13 percent oil soot. Where coal combustion accounted for over 20 percent of the industrial BTU usage, the filters contained from 3 to 30 percent coal combustion products.

Fugitive Emissions

Particulates from fugitive emissions at industrial facilities were found to cause significant TSP levels. The actual impact of fugitive emissions varies greatly with the distance from the source, the windspeed and direction, other climatological factors, and the type of emission. On an average basis, sites in an industrial area that are exposed to fugitive emissions can be expected to have annual mean TSP concentrations 25 $\mu g/m^3$ higher than similar sites not affected by fugitive emissions. Of all the monitoring sites in industrial areas that were reviewed under this study, only those with a fugitive emission influence had annual means above 150 $\mu g/m^3$; all of the monitors with a fugitive emission influence violated the primary annual standard of 75 $\mu g/m^3$.

The control of fugitive emissions is usually pursued under either general nuisance provisions in the regulations, a property line concentration or visibility restriction, or a specific requirement for control of an operation. The effectiveness of each of these types of regulations varies with the authority and enforcement program of the air pollution control agency. Specific requirements are felt to be most effective for major sources where the principal contributors can be identified.

Vehicular Contribution to Ambient TSP

Measurable contributions to the ambient TSP loadings were found to result from motor vehicle activity (tailpipe emissions, tire wear, reentrained dust); in some cases, these contributions were quite high and caused violations of the standards. By far the largest contribution in urban areas was due to reentrained particulates from paved roads. The wheels of vehicles grind up the large, nonsuspendible particles, break up their cohesive bonds, and impart kinetic energy to the particles. The amount of particulate reentrained is directly related to the amount of dirt on the road, the speed of the vehicles, and the level of traffic.

The impact of reentrained dust on the measured air quality depends upon the monitor placement. Between 10 and 100 meters back from streets and arterials, the TSP concentration was found to fall off with the slant distance of the monitor from the road. The contribution from the reentrained dust (in $\mu g/m^3$) can be roughly estimated by 0.1 ADT/SD where ADT is the average daily traffic and SD is the slant distance (in feet). The average impact on monitors reviewed in this study was about 10 to 15 $\mu g/m^3$ in residential areas and 15 to 20 $\mu g/m^3$ in commercial and industrial areas; however, at an individual site the impact may be as much as 50 $\mu g/m^3$.

Other contributions to TSP arising from motor vehicle activity that were studied include tailpipe emissions and tirewear. The impact of tailpipe emissions was quantified using elemental analysis with lead as the tracer element. Commensurate with the level of motor vehicle activity, TSP concentrations due to exhaust averaged about 3 $\mu g/m^3$ in residential areas and 4 to 5 $\mu g/m^3$ in commercial and industrial areas, based on 20 to 25 percent of exhaust particulate being lead. A special study of particle sizes by elemental composition indicated that most lead containing particles have an effective aerodynamic diameter of 0.25 μm; no major difference in lead levels with distance from the road was noticed.

Tirewear was studied using microscopic analysis of selected hi-vol filters. This component of particulates due to vehicular activity had the same neighborhood pattern as the other components - highest in commercial and industrial areas (5 to 10 $\mu g/m^3$ and 3 to 7 $\mu g/m^3$, respectively) and lowest in residential areas (2 to 5 $\mu g/m^3$). The levels of rubber on the filters from monitors located particularly near heavy traffic average twice the levels at other sites. Despite this relationship, significant concentrations of rubber were often found at monitors not obviously influenced by traffic.

A final contribution from motor vehicle activity, which was considered only indirectly because of the lack of appropriate monitor sites in the study cities, was reentrained dust from unpaved roads. While significant TSP concentrations can be expected at monitoring sites near unpaved roads, the current emission factors given in AP-42 provide emission estimates that can be up to 30 times the emissions from traditional sources. Because of the different dispersion characteristics of ground level sources versus stacks and the different particle size characteristics, care must be taken in using these numbers. If these fugitive dust emissions were treated the same as traditional emissions and used in rollback calculations, excessive, undeserved emphasis would be placed on these sources at the expense of control of traditional sources. The use of these numbers should be limited to inputs to models that adequately reflect the deposition and other removal of the particulates.

Construction/Demolition

In nine of the study cities, construction activity (urban renewal, highway, subway, individual buildings) near monitoring sites was analyzed for its ambient air impact. The analyses indicated that construction activity does have an impact on very local TSP levels, but that the effect is not readily predictable. Construction will generally elevate concentrations downwind from the site for distances up to a mile with the amount of increase related to the level of activity, type of activity, distance from the activity, and control measures employed. Monitors within half a mile of construction may have annual geometric means 10 to 15 $\mu g/m^3$ higher than normal. On an average basis, the effect on the citywide TSP level is expected to be only 1 to 3 $\mu g/m^3$, unless major, widespread construction activities such as urban renewal are underway.

As with reentrained dust from unpaved roads, the currently available emission factors for construction activity provide estimates of fugitive dust emissions well above that would appear logical in terms of the TSP levels actually observed. When combined with the calculated emissions from unpaved roads, the fugitive dust emissions in two of the major counties studied amounted to over 60 times the traditionally inventoried emissions.

Monitor Siting

A major consideration in the understanding of the ambient TSP levels in an area is the actual siting of the hi-vols used for assessing the attainment of the standards. The network configuration and the placement of the monitor affects the extent to which the levels reported are representative. The visits to over 150 hi-vols in 14 cities provided a unique opportunity to determine how monitoring networks vary within and between cities. The primary difference noted was the height of the monitor. Typically, hi-vol heights range from ground level to the top of many-story buildings. The median height of hi-vols in the 14 cities ranged from 6 feet in Birmingham to almost 50 feet in Providence. Despite this order of magnitude range, most sites were still within EPA's guidelines for monitor siting.

Local influences are also important when trying to determine the representativeness of the monitor sites. Almost half of the sites visited were felt to have at least one local influence with over one-quarter of the sites judged to have major influences. Because of the frequency of occurrence and range of local influences, some sites were further classified as having "undue" impact; typical TSP loadings due to the undue impact were around 20 $\mu f/m^3$.

Meteorology

The day-to-day, season-to-season, and year-to-year fluctuations in meteorology often confound analyses conducted to determine the cause of TSP levels. In an attempt to quantify these confounding effects, relationships between a number of meteorological parameters and TSP concentrations were examined in several cities. The most detailed analyses centered around the effects of precipitation amounts, heating degree days, windspeed, and the rate at which TSP concentrations return to normal levels following periods of precipitation.

Precipitation was found to be very effective in reducing TSP levels in areas where high concentrations resulted from either industrial or fugitive dust sources. Average concentrations in these areas decreased steadily with increasing 48-hour precipitation amounts. The effect of precipitation was greatest on the day it occurred and lasted on the average about 2 days. In high concentration areas, concentrations measured during the last half of a 48-hour period with precipitation $\geq$ 0.25 in. averaged approximately half of concentrations measured during 48-hour periods with negligible precipitation. Concentrations at typical urban sites on days with measurable precipitation were about 75 to 85 percent of average values for the site and time of year.

The effect of windspeed on TSP concentrations was found to vary with monitor siting and neighborhood characteristics. Very high concentrations of TSP were typically associated with light winds and poor ventilation. In industrial areas, where major contributions were made from point sources, concentrations decreased with increasing windspeed up to about 10 miles per hour; at higher windspeeds, TSP levels appeared to be invariant with average speed, perhaps as a result of a balance achieved between dilution and an increased rate of reentrainment of fugitive dust. In the nonindustrial urban areas studied, no significant relationship between TSP level and average windspeed was found.

A multiple regression analysis was applied to 5-year sets of data from 10 of the study cities. This analysis indicated that a 1-inch increase in the annual precipitation level would decrease the annual TSP concentration by 0.4 $\mu g/m^3$ and that for every 1000 degree-day increase in the annual heating demand the annual TSP concentration would increase 2.5 $\mu g/m^3$.

RECOMMENDATIONS

This study identified several areas requiring increased control emphasis and program redirections, a number of problems needing guidance, and several major research needs. The guidance and research needs can primarily be resolved by EPA, while the control and program recommendations are more appropriately directed to state and local air pollution control agencies.

State and local agencies should concentrate on better defining the cause of the TSP standards nonattainment and should be pursuing more stringent regulations and enforcement in those heavily industrialized areas where traditional sources are major contributors to nonattainment. The agencies' efforts should also be directed at quantifying the contributions from nontraditional sources and developing and enforcing regulations appropriate to these problems; this is particularly important where traditional sources are a minor problem or where they are already in compliance with stringent regulations.

EPA needs to provide more guidance in the following areas: monitor siting; the problem of natural reentrained dust and large particles on short-term standards attainment; the analytical methods available for particulate studies; the interpretation of emission factors currently being used for fugitive dust emissions.

Two major national control and research priorities emerge from this study. A broadly supported effort directed at developing controls for urban reentrained dust and similar nontraditional particulate sources will be required in order to meet the present particulate standard. In addition, reduction of the regional-scale burden of transported and secondary particulates, especially sulfates, should also be pursued if standards are to be attained in the northeast.

SECTION I

INTRODUCTION TO STUDY

This report presents the results of a study conducted under the auspices of the Control Programs Development Division of EPA's Office of Air Quality Planning and Standards. Its overall purpose was to assess the national particulate problem, based on case studies in 14 major urban areas, with emphasis on identifying the factors involved in the attainment or non-attainment of the National Ambient Air Quality Standards (NAAQS) for total suspended particulates (TSP). The study was intended to improve technical understanding of the TSP problem, to provide specific guidance to the states in TSP problem analysis and control strategy formulation, and to develop recommendations for EPA concerning future program direction and research needs. Consequently, this document is directed primarily at those managers and air quality planning specialists at EPA and the various state and local air pollution control agencies who are concerned with the development of TSP control programs.

BACKGROUND

The Clean Air Act, as amended in 1970, provides for National Ambient Air Quality Standards (NAAQS) for major air pollutants, for the definition of Air Quality Control Regions (AQCRs) and for a joint federal-state control program to ensure that the air quality in the various AQCRs throughout the country attains the NAAQS. The Act also provides for State Implementation Plans (SIPs), to be prepared by the states and approved by EPA, which present each state's plan to implement the national standards within the periods specified in the Act — 3 years after approval for attaining the primary or health-related standards and a "reasonable time" for attaining the more stringent (welfare-related) secondary standards.

In April 1971 EPA promulgated NAAQS for five major pollutants, including total suspended particulates (TSP). Subsequently, the states prepared and submitted implementation plans, and the bulk of the provisions of the SIPs relating to TSP control were approved by EPA on May 31, 1972. Thus the date of May 31, 1975, became the anticipated date for most AQCRs to attain the primary standard for TSP, and it is on the occasion of the passing of this date that the present assessment is undertaken.

On the whole, most aspects of the federal-state TSP control effort have been successful. The average annual geometric mean concentration of TSP at urban sites has declined, as seen in Figure 1, from 81 to 68 $\mu g/m^3$ over the 5 year period. This represents a decrease of over 16 percent or, considering only that portion above nonurban background, a 25 percent reduction in the levels above a typical background estimate of 30 $\mu g/m^3$. Nonetheless, by the criterion of actually attaining the standards, there is still a significant number of AQCRs where the control programs have not yet completely succeeded. In 1974, 136 of the 247 AQCRs in the country violated either the annual or 24-hour primary standard, or both, as compared to 112 of the 182 AQCRs in 1970 which reported at least minimal data. It is likely that at least some of the 65 AQCRs which did not report sufficient data in 1970 were violating either or both of the primary standards that year. Nevertheless, the general picture of the attainment status of the AQCRs is that better than half are still violating one or both of the primary standards.

This picture of widespread nonattainment of the standards seems to contradict the picture of decreasing TSP concentrations already mentioned. The two pictures, however, are not really inconsistent, for several reasons. A single site exceeding the specified ambient air quality standards anywhere in the AQCR is sufficient to state that the AQCR is not attaining

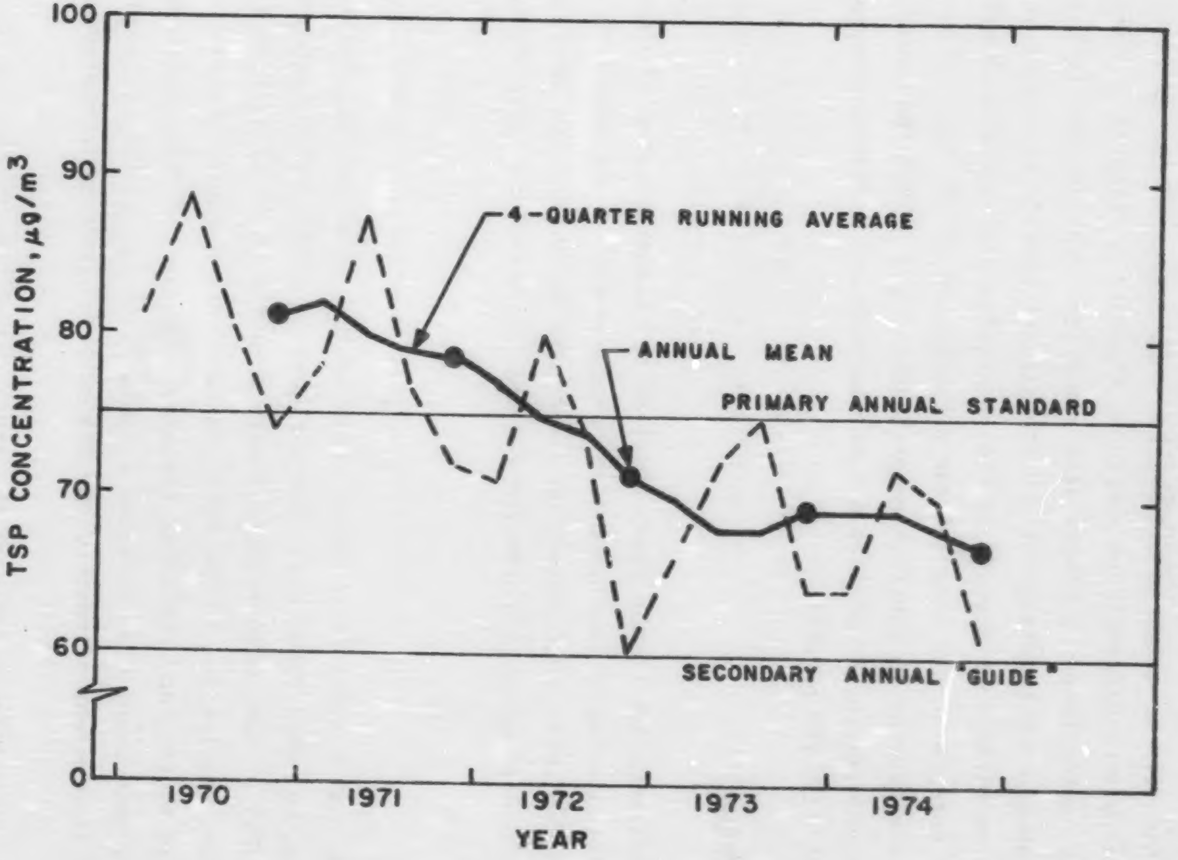


Figure 1. Trend in national average TSP levels (average of 1014 urban sites)

the standards. High ambient TSP levels in an AQCR may have been reduced significantly but not quite enough to attain the standards; or perhaps the majority of sites in a given area have attained the standards, while one isolated site or neighborhood has for some reason failed to do so. It is clearly very difficult to obtain an accurate nationwide picture of attainment status based on simple data summaries, and essentially impossible to obtain any knowledge of the significant factors affecting attainment, the problems encountered, or the successful approaches utilized, without a more intensive study of the distribution of air quality levels and emission sources in specific geographical areas. Thus the present study was undertaken, to provide a more thorough and detailed assessment of the national TSP problem.

STUDY APPROACH

The overall approach to the study involved the identification of those factors influencing the attainment or nonattainment of the standards, the assessment of their significance on a national basis, and the development of a recommended action program for EPA and the state and local control agencies.

The primary source of new information for this national assessment was a series of case studies in 14 major urban AQCRs. These studies involved analyzing, for each urban area, the air quality (1974) and emission data (circa 1974) on TSP, meteorological data from the National Weather Service, the control regulations in the State Implementation Plans, planning materials maintained by EPA, and published technical articles or reference materials. Each city case study also involved a field visit to the city to conduct detailed inspections of most of the TSP monitoring sites in the area.

Although the primary purpose of the study was not to produce new analytical data, several specific analyses were performed. Selected hi-vol filters from each of the 14 case study cities were analyzed by optical microscopic techniques to provide information on the types and sources of the particles collected. Some of these filters were reanalyzed for quality control by the same or other microscopists and laboratories; others were analyzed by EPA for metals and nonmetallic inorganic ions by standard National Air Sampling Network (NASN) analytical procedures. EPA provided information from special field studies in two of the study cities, including wind directional monitoring, diurnal variations in elemental composition, and particle sizing data. Data resulting from all these analyses are compiled in Volume II of this report; discussion of the results is included in this volume or in the individual city volumes as appropriate.

ORGANIZATION OF THE STUDY REPORT

The final study report consists overall of 16 separately bound volumes. This document, Volume I, summarizes the data from the other volumes and should be considered the primary product of the study. Volume II summarizes the analytical data developed during the study, and Volumes III through XVI are the working documents compiled for discussion purposes for each individual city. The subject of each volume is listed below:

Volume I - National Assessment
Volume II - Particle Characterization
Volume III - Denver
Volume IV - Birmingham
Volume V - Baltimore
Volume VI - Philadelphia
Volume VII - Washington
Volume VIII - Chattanooga
Volume IX - Oklahoma City
Volume X - Seattle
Volume XI - Cincinnati
Volume XII - Cleveland
Volume XIII - San Francisco
Volume XIV - Miami
Volume XV - St. Louis
Volume XVI - Providence

The remainder of Volume I is organized as follows:

- Section II - presents the general findings of the study, summarizes the findings in each individual case study city, and identifies the components of the five major factors influencing TSP levels.
- Section III - presents the overall national assessment of the significance of each of the five factors. It places in perspective the components of each of these factors and quantifies their relative contributions to air quality.
- Section IV - summarizes the attainment factors identified in the city studies and the implications of the study for control strategy development.
- Section V - provides the detailed recommendations.
- Appendices - include various supportive and reference materials and detailed discussions of data and analyses used in Section III.

SECTION II

GENERAL FINDINGS OF THE STUDY

The individual reviews of the TSP attainment situation in the 14 study cities provided a wide range of general findings. Some of these findings are specific to individual cities, and others are generally applicable throughout the study cities. The analysis of these findings among the different cities serves as the basis for an interpretation of TSP attainment nationwide. This section summarizes the general findings from the city case studies (reported in Volumes III through XVI) and identifies the major factors affecting the TSP attainment problem.

STUDY CITY ANALYSIS

Selection Process

The 14 cities (AQCRs) used in the case studies were selected to represent a cross section of urban areas. Such factors as proximity to bodies of water, topography, meteorology, degree and type of industrialization, fuel usage, and air quality levels were considered. As shown in Figure 2, the study cities are dispersed around the contiguous 48 states, with many located in the East where a large portion of the population and industry of the United States is concentrated. In nature and density, they range from the old industrial cities of the east coast to the newer, less congested cities of the plains and west coast, and they include a cross section of the climatological regimes of the nation. The cities range in size from Philadelphia, the nation's

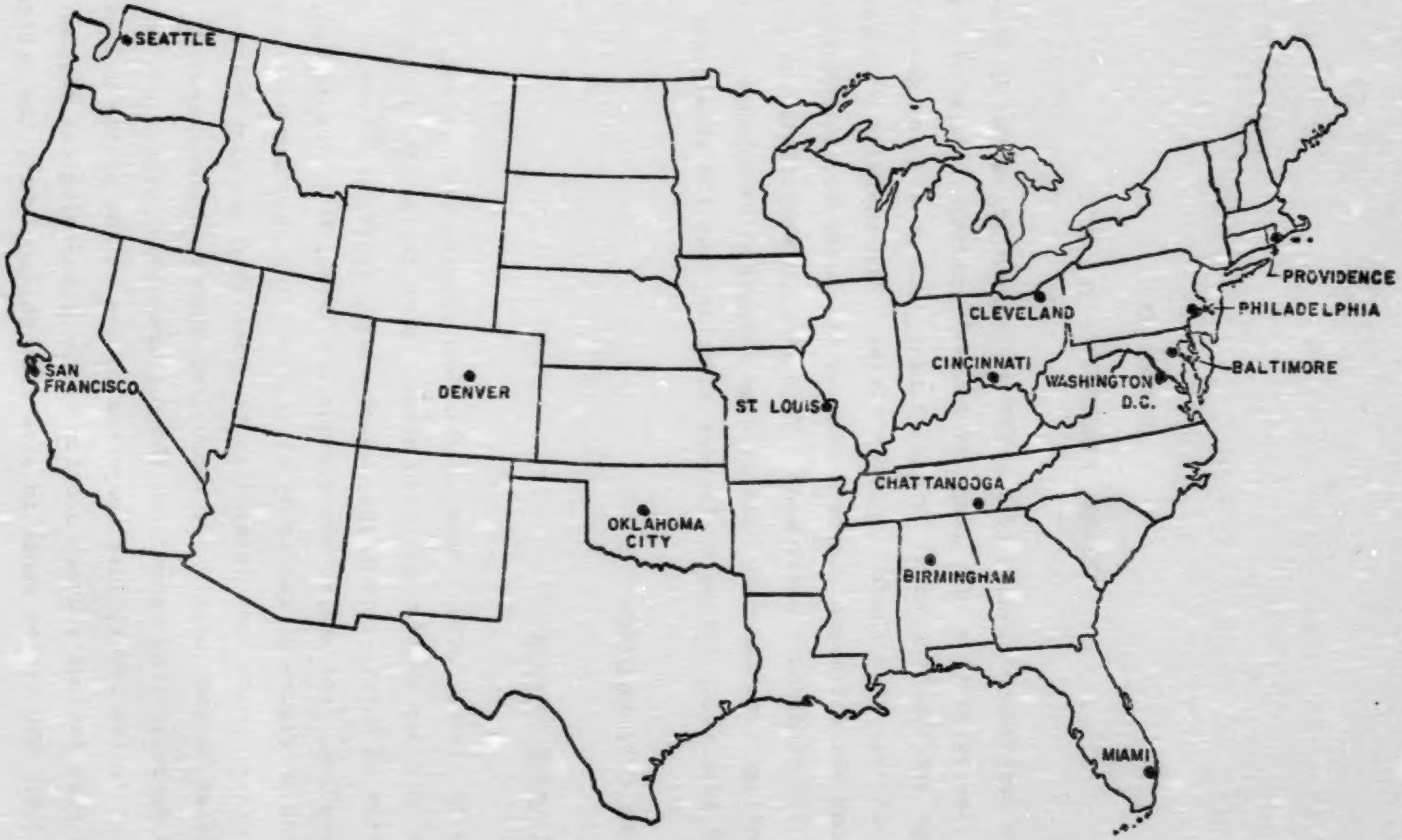

SEATTLE
SAN FRANCISCO
DENVER
OKLAHOMA CITY
ST. LOUIS
CHATTANOOGA
BIRMINGHAM
CINCINNATI
CLEVELAND
WASHINGTON D.C.
BALTIMORE
PHILADELPHIA
PROVIDENCE
MIAMI

Figure 2. Geographical distribution of 14 study cities

fourth largest urban area, to Chattanooga, a small industrial city in the southern mountains. Basic statistics on population, topography, and employment for each of the 14 cities are presented in Table 1.

Two of the major factors that are important in understanding the potential for a TSP problem are the industrial nature and dispersion characteristics of an area. The industrial nature indicates the general level of emissions from major point sources, while the dispersion characteristics dictate the degree to which these emissions affect ambient levels of particulates; Table 2 lists the 14 cities classified according to the possible combinations of these two characteristics. Considered under the category of dispersion characteristics are nonurban particulate levels, extremes in rainfall, sea breezes, and topography. Therefore, cities such as Miami, San Francisco, and Providence, which are dominated by their proximity to the ocean, offer good dispersion qualities; cities with ventilation dominated by valley topography (Chattanooga, Birmingham, and Denver) are considered to have adverse dispersion characteristics. Industrialization was a judgmental categorization based upon the level of employment in the manufacturing sector, the nature of the manufacturing, and the density of emissions.

Table 3 summarizes air quality for the study year (1974), and Table 4 characterizes sources and emissions for the 14 cities, which are grouped by industrialization categories. Other tables and figures giving characteristics of the cities are included in Appendix A.

Methodology of City Visits

The core of the city case studies was one or more field visits to each city. Prior to visiting each study city, a variety of data summaries

Table 1. POPULATION AND PHYSICAL SETTING OF CASE STUDY CITIES

Urban area	1970 population			Population density per sq. mi.		Physical setting		Manufacturing employment (AQCR)	
	AQCR	Rank[a] in U.S.	Central city/county	SMSA	Central city/county	Large bodies of water	Topography	Magnitude, thousands	Percent of total
Philadelphia	5,635,406	4	1,948,609	1357	15,116	Delaware River	Slightly rolling	603	34.1
San Francisco	4,639,949	6	715,674	1254	15,904	Ocean; S.F. Bay	Significant hills	347	24.4
Washington, D.C.	2,862,912	8	756,510	429	12,402	Potomac River	Slightly rolling	53	7.2
Cleveland	3,383,879	9	1,721,300	1329	9,893	Lake Erie	Flat; river valley	484	36.1
St. Louis	2,476,757	10	622,236	547	10,201	Mississipi River	Slightly rolling	279	35.1
Baltimore	2,078,379	14	905,759	917	11,613	Patapsco River, Baltimore Harbor	Slightly rolling	184	29.3
Seattle	1,937,371	17	1,156,633	337	6,350	Puget Sound	Significant hills and valleys	139	26.7
Miami	2,435,089	18	1,267,792	621	9,763	Ocean; Everglades	Flat	144	10.5
Cincinnati	1,660,495	21	924,018	644	5,780	Ohio River	River valley, significant hills	195	37.7
Denver	1,252,007	24	514,678	366	5,418	–	Mountains to west; rolling to east; river valley	99	20.8
Providence	1,502,801	30	580,261	1347	9,896	Narragansett Bay	Slightly rolling	201	44.2
Oklahoma City	783,403	42	526,805	300	579	–	Flat	44	19.0
Birmingham	1,065,599	43	644,991	272	3,785	–	Valley between significant hills	92	31.1
Chattanooga	689,494	96	255,064	307	2,284	–	Valley between sharp ridges	128	52.6

[a] Based on Urbanized Area population.

Table 2. STUDY CITIES BY THEIR DISPERSION AND INDUSTRIALIZATION CHARACTERISTICS

Industrialization	Dispersion characteristics		
	Favorable	Moderate	Adverse
Light	Miami San Francisco	Oklahoma City Washington, D.C.	
Moderate	Providence	Seattle	Chattanooga Denver
Heavy		Baltimore Cleveland Cincinnati Philadelphia St. Louis	Birmingham

Table 3. SUMMARY OF SITES EXCEEDING AIR QUALITY STANDARDS IN 1974

City	Total no. of sites with complete 1974 data	Annual standard			24-hour standard				
		No. sites exceeding standard		Highest geometric mean, $\mu g/m^3$	No. sites exceeding standard		% total obs. > standard		Highest value, $\mu g/m^3$
		Primary, 75 $\mu g/m^3$	Secondary,[a] 60 $\mu g/m^3$		Primary, 260 $\mu g/m^3$	Secondary, 150 $\mu g/m^3$	Primary	Secondary	
Heavily industrialized									
Cleveland	25	12	21	175	6	15	4.7	17.6	534
Birmingham	13	11	11	144	7	11	NA[b]	NA[b]	499
Philadelphia	10	7	9	122	4	8	NA[b]	~8	624
Baltimore	29	9	14	134	6	14	0.9	7.6	NA[b]
St. Louis	31	15	26	158	3	13	1.1	8.7	NA[b]
Cincinnati	25	8	21	130	0	7	0.1	4.2	296
Moderately industrialized									
Chattanooga	12	5	5	101	1	7	0.9	6.9	434
Denver	22	14	21	131	13	22	NA[b]	NA[b]	565
Seattle	10	2	4	105	2	5	0.3	0.8	320
Providence[c]	21	1	5	88	0	1	0	0.8	173
Lightly industrialized									
Washington, D.C.	9	2	5	102	9	9	2.2	NA[b]	527
Oklahoma City	14	5	6	107	5	13	0.7	5.5	NA[b]
Miami	17	2	7	86	0	3	0.2	1.8	NA[b]
San Francisco	17	0	2	74	3	10	0.2	1.3	286

[a] The secondary annual is a guide, not a standard.

[b] NA - Raw data not available.

[c] Totals are for statewide monitoring network.

Table 4. SOURCE AND EMISSIONS CHARACTERIZATION OF STUDY CITIES

City	Major point sources	Predominant fuels[a]		Traditional sources, emission density TPY/sq. mile	Compliance comments
		Residential	Industrial		
Heavily industrialized					
Cleveland	Steel mills, utilities, chemicals	Gas	Gas, coal	335	About 1/3 of major sources in compliance; smaller sources (including incinerators) unknown
Birmingham	Steel mills, cement	Gas	Gas	488	Most sources under compliance schedules; compliance about half complete
Philadelphia	Refineries, coking, smelting, chemicals	Oil	Oil, gas	245	Most sources in compliance
Baltimore	Steel mills, incinerators	Gas, oil	Oil	240	Most sources in compliance, a few under plans for compliance
St. Louis	Coking, steel mills, grain handling	Gas	Gas	411	Most sources in compliance
Cincinnati	Utilities, manufacturing	Gas	Gas, coal	135	Most sources in compliance; rest (including several large sources) expected within 2 years
Moderately industrialized					
Chattanooga	Foundries, cement, minerals	Electricity	Gas	88	Most sources in compliance
Denver	Utilities	Gas	Gas	60	Most sources in compliance
Seattle	Manufacturing	Oil	Oil	37	Most sources in compliance
Providence	Utility, foundries	Oil	Oil	30	Compliance status not certain - most seem to be in compliance
Lightly industrialized					
Washington, D.C.	Utility	Gas	Gas, oil	92	Most sources in compliance
Oklahoma City	Utilities, grain, asphalt	Gas	Gas	2	Most sources in compliance
Miami	Minerals	Electricity	Gas, oil	30	Most sources in compliance
San Francisco	Minerals, chemicals	Gas	Gas	60	Most sources in compliance

[a] Those fuels whose usage is greater than 1/3 of total Btu's.

and analyses were prepared and studied, using data on air quality, emissions, and compliance that were provided by the Project Officer from EPA's AEROS data banks; local agencies were allowed to review, comment on, or revise the data as appropriate. Air quality and emission data were studied for patterns and trends, both temporal and geographic. Emission and compliance data were used to consider patterns of enforcement and compliance.

The primary purpose of the field visits was to study in detail the hi-vol monitoring network and to gain a degree of understanding about the overall nature of the study city and the general patterns of land use, such as the relationships among industrial and residential areas. During the field visit, the study team also consulted with technical staff members from the appropriate pollution control agency concerning those areas where the EPA data base was incomplete or anomalous, and a member of the agency staff usually accompanied the visiting team on the monitoring site study visits. Additional efforts during the study visits in some cities involved seeking data on traffic volumes, street cleaning practices, etc., as appropriate to the particulate air pollution problem in the city. In most cases, historical hi-vol filters from agency files were also selected and brought back for analysis.

Following the field visit, the monitoring site information was reviewed and compiled into an overall site classification analysis. Other information and data obtained were integrated with that previously available, and an overall assessment concerning the factors affecting attainment was formed. The data summaries, analyses, and conclusions relating primarily to a single city were then compiled into a working document for each of the study cities; these documents comprise Volumes III through XVI of this report.

City Study Findings

The results and findings of the city case studies are quite varied in detail and in breadth of applicability. Those specifically relevant to only the individual city are presented in the separate volume for that city. Those that are of significance for the overall conclusions of the study are summarized here. Appendix A presents tabular summaries of other data relevant to the various study cities.

Baltimore - A heavily industrialized city, Baltimore has had an intensive pollution control program since the mid-1960s. This has contributed to a 50 $\mu g/m^3$ decrease in the annual average at the center-city NASN site over this time. Nonetheless, the annual primary standard is still exceeded at nine sites, mostly in the center city and harbor industrial areas. Under vigorous enforcement of very stringent regulations, most of the city's major industries and the municipal incinerators have reduced their emissions an average 70 percent; on the other hand, emissions from the iron and steel industry, which comprise 85 percent of the total point source emissions in the metropolitan area, have been reduced only 15 percent. One steel mill clearly contributes to TSP problems at several industrial sites; however, at the industrial site with the highest annual average (134 $\mu g/m^3$), local fugitive dust emissions also make a significant contribution to the elevated levels. Three or four sites located in the urban center appear to be above the standard without any particular local source influence. Part of this urban increment is probably due to the use of oil for residential space heating, one category of source which is not closely regulated; however, much of the TSP measured at these sites must simply be attributed to the dense level of activity in the urban area. TSP levels at the center city site are further elevated by immediately adjacent expressway construction.

Birmingham - The improvement in air quality has been substantial in Birmingham, but still only two suburban sampling sites met the annual primary standard in 1974. Values have fallen from around 300 to 145 $\mu g/m^3$ at the most polluted industrial site, and commercial and other industrial sites have shown similar decreases of roughly 50 percent. Four industrial sites reported 1974 annual geometric means over 125 $\mu g/m^3$ because of proximity to the predominant steel industry and the associated coking and foundry operations, which account for the bulk of point source emissions. Stringent regulations and vigorous enforcement have resulted through 1974 in about half the emission reduction ultimately expected, with the balance anticipated over the next 2 years as compliance plans are completed. The general effect of dense urban activity on TSP levels is not seen clearly in Birmingham because of the much larger industrial process contribution, but may well be a problem for future consideration.

Chattanooga - A moderately industrialized city, Chattanooga has also experienced a significant decline in TSP levels due to a trend away from the use of coal and, more recently, to vigorous control of industrial emissions. However, five of twelve sites, all in industrial or commercial locations, continue to exceed the annual primary standard with annual means between 80 and 101 $\mu g/m^3$. Of these, two are affected significantly by local industrial sources - a quarry and a cement plant - and the others by general downtown commercial activity or major traffic arteries. An overall difficulty relates to adverse topography and meteorology; particularly stringent emission control for both industrial and fugitive sources will be needed to meet the standards under the adverse dispersion conditions prevalent in Chattanooga.

Cincinnati - The TSP trend has been downward since the mid-1960s, with the NASN center-city site experiencing a 70 $\mu g/m^3$ decrease in its annual average. The major industries - transportation equipment, fabricated metals, paper, chemicals, and a small power plant - have made large reductions in particulate emissions, primarily by switching from coal to natural gas or otherwise reducing fuel combustion emissions. Nonetheless, seven sites still exceeded the annual primary standard in 1974 at locations in the central business district (CBD) and the industrial valley, with one site measuring 130 $\mu g/m^3$ as an annual average. All sources are expected to come into compliance over the next 2 years, during which time further reductions are expected. However, full compliance may not result in standards attainment because fugitive emissions and fugitive dust are likely to remain a significant source of particulates at several sites in the CBD and industrial areas unless control measures are taken.

Cleveland - Although there has been a fairly steady decrease in ambient TSP levels since the early 1960s, 1974 levels at 12 of 25 sites in the county violate the annual primary standard. The city is large and heavily industrialized, with an emission density of 335 tons per year per square mile, and has the highest annual average TSP levels of the cities studied (175 $\mu g/m^3$). Primary metals, fabricated metal products, machinery and transportation equipment are the predominant industries and, along with the utilities, the largest sources of particulate emissions. Control efforts by a few problem sources have resulted in substantial emission reductions, but overall control efforts have not been effective. While other factors, such as fugitive dust, may very well become apparent as the massive industrial contribution is reduced, the most important factor influencing nonattainment in Cleveland is the level of industrial emissions. These include not only major point sources but also industrial fugitive emissions and the vehicle-entrained fugitive dust emissions associated with industrial areas.

Denver - In contrast to most other areas studied, the Denver AQCR has shown no definitive trends in TSP levels during the past 6 years. Despite its low level of industrialization, Denver has had TSP concentrations well above the annual standards since levels were initially monitored in 1957. In the long term, Denver County has shown approximately a 20 percent improvement in its air quality since 1965. However, in 1974 only one out of 22 sites, a site located in a rural area, met the secondary standard; 14 of the sites exceeded the primary standard. This general lack of attainment of the standards has been commonly attributed, in part, to the arid climate which allows easy reentrainment of fugitive dust. The highest annual mean (131 $\mu g/m^3$) was recorded at a site obviously influenced by fugitive dust, where 36 percent of the observations were above the secondary 24-hour standard and 14 percent were above the primary 24-hour standard. The impact of both fugitive dust and traditional industrial source emissions is spread throughout the region because of the poor ventilation and topographic characteristics of the region. In addition, an inadequate data base, from which the initial implementation planning was done, has contributed to the problem of attainment in the region. Several emission inventories have been compiled for the region over the years, but the continuing iterations resulted in a lack of consistency, especially between area source inventories, and has prevented the determination of emission trends. Despite the problem of appropriate emission data, major sources are assumed to be generally in compliance with the regulations and the state agency is now pursuing fugitive dust sources.

Miami - The highest ambient TSP levels in Miami have been fluctuating near the standards for several years. The area is generally free of major TSP point sources; the largest emitters are stone and gravel quarrying operations. During 1974, two sites failed to meet the primary standard. The higher, with an annual geometric mean of 86 $\mu g/m^3$, was located in a light industrial-commercial area, on a major arterial highway, with an auto junkyard and a variety of other unpaved fugitive dust sources in the immediate vicinity. The other site was at a highway intersection in a rural area, near a major aggregation of cement plant operations. A special study conducted by the Dade County agency indicated, however, that the cause of the high levels was not the cement plants themselves, but rather the reentrainment by traffic of material spilled on the highway by the sizable number of trucks turning at the intersection.

Because of the general lack of point source emissions, the relative homogeneity of the area, and particularly the consistency of the monitor heights, Miami provided a good opportunity to study that portion of urban TSP levels that appears to result from aggregate urban activity. Two measures of urban activity were found to correlate well with the TSP values at the various sites: traffic volumes and the proportion of adjacent land used for streets and parking.

Oklahoma City - An institutional, light-industrial city where gas is the predominant fuel, Oklahoma City nonetheless has five of 14 sites where the annual primary standard is exceeded. TSP levels at the NASN site show only a slight downward trend over time, reflecting the low density of readily-controlled industrial sources and the inability to comprehensively control fugitive dust. The high levels at the sites over the standard can be attributed in part to either significant traffic exposure, adjacent construction, or (at three of the sites in the center city) a combination of central business district traffic and urban renewal activity. The dry climate and high winds tend to maximize natural entrainment of dusts, but the urban pollution problem is not primarily due to particulates from the surrounding rural area.

Philadelphia - Air quality has been steadily improving in the city; annual average TSP concentrations at the NASN site are down over 100 $\mu g/m^3$ since 1957. However, the annual primary standard was met at only three of the 10 monitors operating throughout 1974. Of these three monitors, all in residential areas of the city, only one met the secondary annual standard with a value of 59 $\mu g/m^3$. The large improvements in air quality have been directly paralleled by reductions in the inventoried emissions due to stringent controls on industry (fabricated metals, machinery, electrical equipment, petroleum) and large incinerators, phasing out of small incinerators and coal burning, and fuel switching in power plants. The lack of attainment of the standards, despite stringent regulations and effective enforcement, reflects the generally high level of TSP entering the city from outlying industrial activity (40 to 50 $\mu g/m^3$) and the activity associated with an urban environment, including space heating and vehicular traffic. Small residential boilers have not been under any control other than visible emission regulations. Vehicular traffic was shown to contribute up to 50 $\mu g/m^3$ to the measured levels of TSP for monitors close to the street. In addition, fugitive emissions from stockpiled materials and a grain-handling operation were believed to be major influences on the monitor with the highest annual mean (122 $\mu g/m^3$).

Providence - A downward trend in TSP concentrations has been occurring since the mid-1960s, and only one sampling site exceeded the annual primary standard in 1974. A utility, municipal incinerators, and some industrial processes - primary metals, fabricated metal products and electrical equipment - are the largest point sources of particulate emissions. Fuel switching and the closing of incinerators are apparently responsible for the emission reductions and the corresponding air quality improvement, although the compliance status of a number of sources is unknown. The one site which exceeded the annual primary standard with an average of 88 $\mu g/m^3$ is excessively influenced by a major expressway immediately adjacent. Oil-fired space heating is a significant source category which has not received much attention in light of the general standards attainment. Some portion of the overall favorable picture may be due to a generally high average sampler height compared to other cities and to relatively good dispersion characteristics.

St. Louis - The TSP trend has been downward since the mid-1960s with the NASN site experiencing a decrease of 80 $\mu g/m^3$ in its annual geometric mean. Fifteen sites, however, violated the annual primary standard in

1974. Transportation equipment, primary metal, fabricated metal products, and machinery industries are the largest sources of particulate emissions, and fuel switching and industrial process controls have accounted for much of the emission reductions. The majority of the sources in the Missouri portion of the AQCR are believed by the local agencies to be in compliance; however, the St. Louis City and County regulations are among the least stringent of those studied. The Illinois portion is less advanced in terms of degree of compliance, because control efforts started later, but it should become comparable to Missouri by maintaining its program of stringent regulations and strict enforcement. The fact that high TSP concentrations are still being experienced despite the presumed general compliance indicates that other factors are important. These include the relatively weak regulations and the lack of source testing as a method for compliance determination in Missouri, as well as the general tendency of dense center-city sites to be systematically higher due to urban activity.

San Francisco - San Francisco is the one study city that met the annual primary standards during 1974. Despite its large population and generally dense urbanization, the San Francisco AQCR has never had a serious problem with particulates, due largely to the very clean background air it receives from over the Pacific Ocean and the low level of heavy industrial activity. Air quality trends at the San Francisco NASN site have shown a decrease of about 20 $\mu g/m^3$ from a high of 73 $\mu g/m^3$ in 1957. This decrease of over 30 percent in above background levels is comparable to the trends reported for emission reductions. These emission reductions occurred in part (pre-1970) because of extensive fuel switching by the residential sector from coal and oil to gas and electricity and (since 1969) because of controls on industrial processes and burning of materials. These controls are no more stringent than the average found in the cities studied, but their success is maximized by an extensive, computerized enforcement program conducted by the Bay Area Pollution Control District. In addition, regulations have been revised over time as data indicate that more stringent controls are feasible and warranted. The combination of the above factors and the low level of emissions (170 tons/day for the entire AQCR) meant that only two monitors out of 17 exceeded the annual secondary standard, and no monitors violated either the 24-hour or annual primary standards. The highest annual geometric mean of 74 $\mu g/m^3$ was measured at a station highly influenced by fugitive dust. This monitor and many others in the network are often subject to poor ventilation conditions because of the valley topography; even so, the 24-hour secondary standard was exceeded less than 1 percent of the time in 1974.

Seattle - While it also has the advantage of being a west coast city, unencumbered with TSP transport from other areas, Seattle is further inland than San Francisco and significant industry is concentrated in a valley adjoining the city. However, the higher level of annual precipitation helps keep the TSP concentrations down around those measured in the San Francisco area. Air quality levels have shown fairly steady downward trends over the years with a 50 $\mu g/m^3$ decrease in the annual average at the NASN site since 1957. Of the 30 sites in the AQCR, the annual primary air quality standard was exceeded at two stations and the annual secondary standard was exceeded at another three sites. The highest concentrations (60 to 105 $\mu g/m^3$) occur in the industrial valley and the lowest levels (35 $\mu g/m^3$) in the residential areas out of the valley. Estimates of emissions indicate that most traditional source sectors - industrial processes, fuel combustion, solid waste disposal - have had some reductions contributing to a 40 percent overall reduction in inventoried emissions since 1969. These changes in emissions since 1969 have not been reflected in the air quality, which has seen increasing TSP levels in 1973 and 1974. The general process weight rate regulation under which process sources are controlled was found to be much less stringent than those normally applied; however, the Puget Sound Air Pollution Control Agency has the additional restriction on emissions of 0.03 grains/scf, one of the most stringent requirements in the country. Fugitive dust due to vehicular traffic has also been cited as one of the problems in the industrial valley. The monitor with the highest annual mean (105 $\mu g/m^3$) is located approximately 25 feet back from a heavily traveled road; a location 100 yards back from the road has levels about 40 percent lower.

Washington, D.C. - While Washington has never had the major TSP problem of other cities because of its nonindustrial nature, two sites in the city exceeded the annual primary standard in 1974. There has been a slight downward trend since the early 1960s as coal use decreased and higher grade fuels were substituted, but two center-city sites continued to exceed the primary standard in 1974. Control regulations are stringent, and large emission reductions have resulted from the closing of incinerators and fuel switching; most sources seem to be in compliance. The cause of nonattainment at the two center-city sites is a mixture of urban activities. Demolition and construction associated with urban renewal was prevalent for several years, and has been more recently supplemented by construction of the METRO transit system. In comparison with other cities, traffic would appear to be an expected problem. However, any clear demonstration of that influence is precluded by the extreme heterogeneity of monitoring site locations, with almost all monitors located very high, very remote from the traffic, or both.

Particle Characterization

As mentioned in Section I, optical microscopic examination was undertaken on selected hi-vol filters from each city. A total of 300 filters were selected, from several representative sites in each city, and the results were subjected to quality control checks. A summary of the filter analyses and the results of the quality control are presented in Appendix B of this volume, and a more detailed presentation is included in Volume II of this report. The reader is advised, however, to consider the results of the quality control program which suggests that the data may not be construed to be more than semi-quantitative in nature.

In Table 5, the microscopy results for each city have been averaged by the generic type of material present. These composite results show the highest percentage component to be mineral matter. Sources of mineral matter include windblown soil, reentrained dust from streets, fugitive dust from construction and demolition, and such industrial sources as primary metals and mineral products industries and material storage piles. Appendix B gives a more detailed breakout of these components. The higher values for mineral matter in Denver and Oklahoma City support the theory that fugitive dust sources are particularly important in arid areas.

It should be emphasized that the optical microscope does not allow identification of particles smaller than about 1 μm, so the analytical data is representative of only the supermicron portion of the particulate. Based upon the experience of the microscopists involved, an average of about 15 percent of the mass is submicrometer in size and invisible to the analyst. Therefore, in applying the component percentages, it was assumed that 15 percent of the mass is invisible to the microscopist. Table 6 shows the results of this procedure as applied to a categorization of the components by site type for all sites studied in the 14 cities. Although the results are listed as average loadings, it should be pointed out that the filters selected for analysis were not necessarily average or even typical. Within each study area, the selection of samples was normally limited to filters from the 3 consecutive months of 1974 with the highest average TSP level and the 3 consecutive months of 1974 with the lowest average TSP level; the filters selected from these periods were usually from days with average to high TSP levels. This was done in an attempt to discern differences in particle type at specific sites as a function of TSP loading. The composited results may or may not be representative of the annual average.

Particle Size — The average particle size for each of the major visible components is presented in Table 7. In general, mineral constituents had the smallest particle size, and biological materials and rubber the largest. The differences between sizes reported for the aggregate categories and the subcategories is not significant. Although the average size of the mineral fraction, 8 μm, is consistent with the average sizes

Table 5. COMPOSITE SUMMARY OF MICROSCOPIC ANALYSIS IN 14 CITIES, $\mu g/m^3$

City	Minerals		Combustion products		Biological material		Miscellaneous	
	Average	Range	Average	Range	Average	Range	Average	Range
Heavily industrialized								
Cleveland	51	28-85	40	10-70	1	<1-5	8	tr-22
Birmingham[a]	66	14-90	22	2-86	2	0-8	10	0-50
Philadelphia[a]	64	6-93	33	6-89	1	0-10	2	0-30
Baltimore[a]	69	52-88	25	11-61	3	<1-11	3	0-26
St. Louis	75	21-99	21	1-79	<1	0-5	4	0-10
Cincinnati	51	24-88	44	9-84	1	<1-5	4	<1-20
Moderately industrialized								
Chattanooga	36	3-96	35	8-78	16	0-90	13	0-45
Denver	81	62-97	7	1-19	1	0-7	11	0-32
Seattle	60	30-96	27	1-62	3	tr-24	10	<1-40
Providence	64	28-92	22	4-68	1	0-5	13	0-35
Lightly industrialized								
Washington, D.C.	70	39-87	23	5-49	5	<1-47	2	<1-25
Oklahoma City	88	63-99	8	1-31	<1	<1-4	4	<1-30
Miami[b]	79	75-83	9	7-12	<1	<1	12	10-15
San Francisco	52	29-73	29	10-50	3	tr-10	16	0-35
All cities	65	3-99	25	1-89	3	0-90	7	0-50

[a] Excludes analyses of NASN site filters

[b] Analyses of NASN site filters only

Table 6. ESTIMATES OF AVERAGE FILTER LOADINGS BY SITE CLASSIFICATION[a]

Components	Average loading, $\mu g/m^3$			
	Commercial	Residential	Industrial	Undeveloped
Mineral	64	51	87	66
Combustion products	27	19	42	6
Biological material	2	3	3	<1
Misc. (mostly rubber)	9	5	9	<1
Assumed < 1 μm	19	14	25	13
Total	120	92	166	86

[a] Based on a total of 300 filters analyzed.

Table 7. COMPOSITE SUMMARY OF PARTICLE SIZE BY COMPONENTS[a]

Component	Average size, μm	Average size range, μm	No. of filters included in averaging
Minerals	(8)	<1-62	153
Quartz	11	2-65	154
Calcite	9	1-45	148
Hematite	3	<1-39	89
Combustion Products	(5)	<1-58	92
Oil soot	13	4-106	107
Coal soot	30	6-66	52
Glassy fly ash	12	2-38	35
Biological Material	(24)	5-82	13
Pollen	35	13-39	15
Rubber	(43)	13-135	94

[a] Based on a total of 300 filters analyzed.

of the principal components, the average size reported for combustion products, 5 μm, is noticeably lower than the average size of the individual components within that group. This is because the filters on which sizing of the individual components was done are not necessarily the same filters that comprise the aggregate combustion products group. For some filters the size range was reported only for the combustion products group as a whole because the individual components comprised less than 5 percent of the observed particulate. The average size of the biological material is quite large but understandable in terms of its source and aerodynamic shape. The very large average particle size reported for rubber, however, is somewhat harder to understand. The generation of large rubber particles by mechanical abrasion is easily understood, but it is difficult to explain how such large particles can be transported over substantial horizontal or vertical distances.

Quality Control — The reader is cautioned to review Appendix B regarding the results of quality control procedures used in the microscopic examination. Briefly, it was found that the replicability of the results of analyses of individual samples varied considerably with some results quite far apart. Although the compositing of results from many filters to obtain average results minimizes any systematic bias among microscopists and laboratories, the results should not be construed to be more than semi-quantitative in nature.

SUMMARY OF FACTORS AFFECTING ATTAINMENT

The purpose of the city case studies was to identify and study the various factors, problems, and issues concerned with attaining the TSP standards as they were experienced in each city. Since the 14 cities cover a broad range of city characteristics and hence represent a variety of situations with respect to TSP air quality and its determinants, analyses of the factors in the various cities can be drawn together for an overall assessment of the TSP attainment situation in the study cities and, by extrapolation, throughout the nation.

Following the analyses of the study cities, a number of factors were identified as significant for standards attainment. Many of these had been first identified in the preliminary literature review and were then followed up in the city studies; a few others were identified in the course of one or more of the city studies. The principal issues are listed below, grouped into five major categories that will subsequently provide a framework for the more detailed discussions in Section III.

Large Scale Influences

Large scale influences include those factors that dominate an area much larger than the urban areas being studied. They include natural, transported, and secondary particulates. The differing influences of these factors in various urban areas can cause significant differences in the ability to control the local TSP problem. Their effect on urban levels is generally estimated by measuring air quality in nonurban areas. The average nonurban particulate level for the 14 study cities is between 25 and 30 $\mu g/m^3$; however, values ranged from less than 15 $\mu g/m^3$ on the west coast to roughly 35 $\mu g/m^3$ in the metropolitan northeast. The three major large scale factors are described below:

- Natural particulates — A major factor that can have significant impact on standards attainment is the magnitude of the natural TSP level in the incoming air masses. The west coast cities benefit from having a very low (global) particulate level, while cities in the central plains or the east have additional continental contributions.

- Transported primary particulates — Cities in the eastern metropolitan complex have the further problem of manmade particulates being transported from neighboring urban areas without space for adequate dilution. Therefore, these cities have an impaired capability for managing their own air quality.

- Secondary particulates — Levels of particulates such as sulfates, nitrates, ammonium and some organic compounds, which are generally believed to be formed as secondary particulates, indicate again that cities in the east are receiving increased TSP levels from other areas. These particulates are formed both in transport and locally from gaseous emissions not traditionally controlled in TSP standard attainment strategies.

Traditional Source Factors

Much of the problem of standards attainment in several of the 14 study cities is attributable to emissions from those sources — industrial processes, fuel combustion, incineration — that have traditionally been considered subject to pollution control efforts. Cities with heavy industrial activity were found to have citywide TSP levels averaging from 10 to 50 $\mu g/m^3$ above the levels in cities with little or no industry; sites particularly close to heavy industrial activity averaged up to 25 $\mu g/m^3$ higher than other industrial sites. Specific nonattainment factors related to traditional source emissions include the following:

- Industrial emissions — In several cities, widespread industrial emissions were obviously the major share of the overall urban problem; in other cities more isolated industrial emission problems were responsible for local nonattainment. The most apparent problems were the steel industry, with associated coking and foundry operations, and the various minerals handling industries, such as cement and asphalt plants and stone and gravel quarries.

- Fugitive emissions — Several sites, generally near industrial areas, were significantly affected by fugitive emissions from such sources as materials stockpiles, coal loading operations, blast furnace slips, rock crushing and loading, and similar uncontained industrial processes.

- Fuel oil combustion — In several cities there was concern over the degree of impact from oil combustion. In coastal cities, oil is frequently used for space heating, and the smaller residential oil burners are typically not controlled as pollution sources. In midwestern cities where coal is used significantly, even very major oil-fired combustion units, such as utility boilers, have sometimes been ignored as sources because they are cleaner than equivalent coal-fired units.

- Fuel use trends — One positive influence on standards attainment in several cities is the on-going trend toward cleaner fuels, especially the shift from coal to gas in small units. This is a continuation of a trend spanning many years, fueled by factors of convenience and economic affluence.

- Ineffective control programs - In at least one instance, a major factor in failing to attain the standards is the overall lack of any effective control program or enforcement effort.

- Lack of adequate time for control — In some instances, failure to meet the standards is due to having insufficient time since the inception of control efforts for even an outstanding control program to cope with a major TSP problem.

- Inadequate compliance determination — In most of the study areas, the process of verifying that a source is in compliance and remains so appears to be somewhat haphazard. Most agencies have less firm knowledge on such matters than seems desirable

- Inadequate regulations — In some cases, relatively nonstringent regulations inhibit meeting the standards by requiring less reduction in emissions than is necessary to meet the standards.

- Inadequate data base — In some cases, planning for air quality management and standards attainment is inhibited by the lack of an adequate data base. Usually involving emissions rather than air quality data, this lack can be so extreme in some cases that it must be construed as a major misunderstanding as to the nature of the TSP problem being faced.

Nontraditional Factors

Even with the nonurban, large scale particulate concentrations and the emissions from traditional sources taken into consideration, analysis of many of the monitoring sites in the 14 study cities indicated that other factors, not traditionally considered, were producing TSP levels that were typically 25 to 30 $\mu g/m^3$ higher than expected. Such levels could often be attributed to specific sources such as construction activity or localized fugitive dust emissions, but in many cases the elevated concentrations were simply the result of many uninventoried activities in urban areas. Specific factors identified include:

- Localized fugitive dust emissions — A number of sites in various cities were prevented from attaining the standard at least in part by emissions from bare unvegetated lots, unpaved parking areas and roadways, heavily traveled expressways, and similar local sources of entrained dust.

- General urban activity - In most cities, ambient TSP levels in the densest part of the city are higher than expected, influencing attainment at a number of commercial and dense residential sites in almost every city. The best immediate presumption is that this excess concentration represents the combined, well-mixed influence of higher levels of traffic and similar types of urban activity that tend to be greater in the more dense central part of the city.

- Construction activity - Several sites, often center-city commercial sites, were hindered in meeting the standard by dust entrained from construction sites of various types, including urban renewal, small building construction, and highway and subway construction.

In addition to the above factors, which are all related to sources of particulate emissions, other factors were found to affect the real or apparent TSP problem. As discussed in the selection of the cities, the meteorology and climatology of a region can help to aggravate or ameliorate the TSP problem; the dispersion characteristics and precipitation levels are the most prominent influences. The design of the monitoring network configuration and the actual placement of monitors are also important in conceptualizing what the TSP situation is. The general findings from the city studies for these factors are summarized below.

Meteorology and Climatology

- Dispersion conditions — The overall pollutant dispersion characteristics can have significant effects in either direction; in the southern mountain area, the attainment is clearly more difficult because of adverse meteorology and topography, whereas in the coastal and great plains areas the opposite is true.
- Precipitation — Frequent, significant precipitation is apparently a help in attaining standards, while arid conditions are a detriment.

Monitoring Considerations

- Inappropriate sampler heights — One of the more common problems with hi-vol network design is the question of consistent, appropriate sampler heights. If the hi-vols are strikingly higher or lower than typical, the recorded TSP levels will be artificially decreased or elevated in comparison to other cities. Similarly, if there are striking height differences within one urban area, there will be difficulties in adequately planning for standards attainment and in accurately assessing progress.

- Network design — As the TSP levels vary from monitor to monitor, and generally around the city, it is important to ensure that those areas of maximum TSP concentration are monitored. Some cities located monitors with the help of extensive modeling efforts, while others picked convenient locations.

Figure 3 is a schematic sketch of the interrelationship of these five major groups of factors. It is intended as a minemonic device to emphasize that three of the factors are actual components of the particulate matter, while the other two are distorting influences.

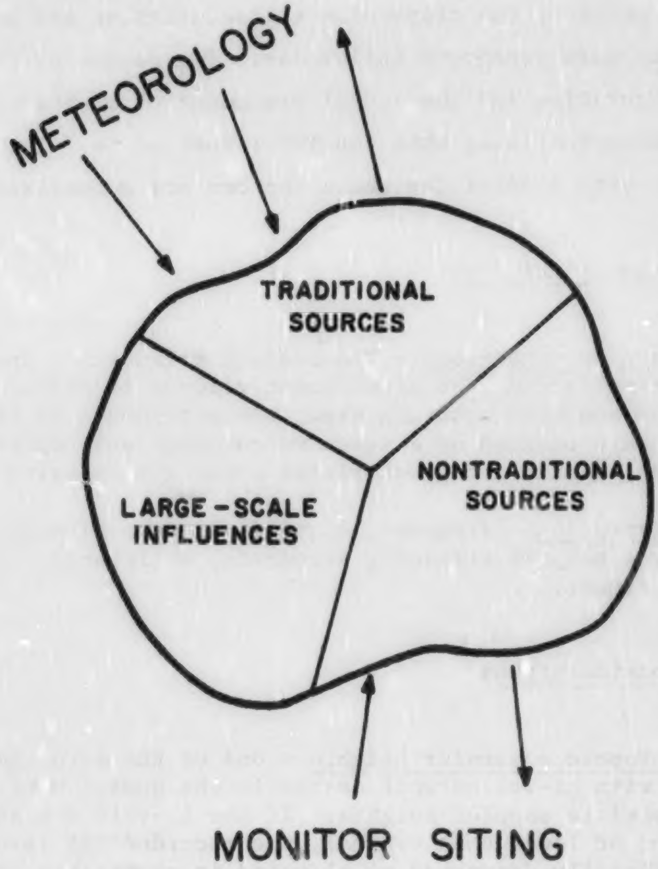

METEOROLOGY
TRADITIONAL SOURCES
NONTRADITIONAL SOURCES
LARGE-SCALE INFLUENCES
MONITOR SITING

Figure 3. Schematic relationship among five major factors

SECTION III

ASSESSMENT OF FACTORS AFFECTING ATTAINMENT

This section assesses the significance of the five major factors identified with respect to the attainment or nonattainment of the ambient standards. For ease of readership, much of the more extensive analytical and discussion material has been collected into appendices, of which this section can be considered a summary.

Since the air quality standard makes no distinction among particulates from various sources, any source of particulates must be considered to be contributing to standards nonattainment. The extent that the source or source category contributes to the measured TSP levels at the point in question is the same as its contribution to standards nonattainment. Therefore, the assessment of the typical contributions from the various factors can be seen as the determination of the contributions of the various factors to an overall typical TSP concentration. This viewpoint, along with a determination of how the various factors affect variations in TSP levels, provides a useful discussion framework, which is used throughout this section. The large number of monitoring sites (154) visited and studied throughout the country provided a unique opportunity for developing an understanding of the individual factors affecting the measured TSP levels. From an analysis of the data, the city characteristics, and the monitoring site locations, the components of the TSP at different types of sites were estimated.

The most obvious difference among sites is the nature of the neighborhood in which they are located. Figure 4 shows the average of the annual

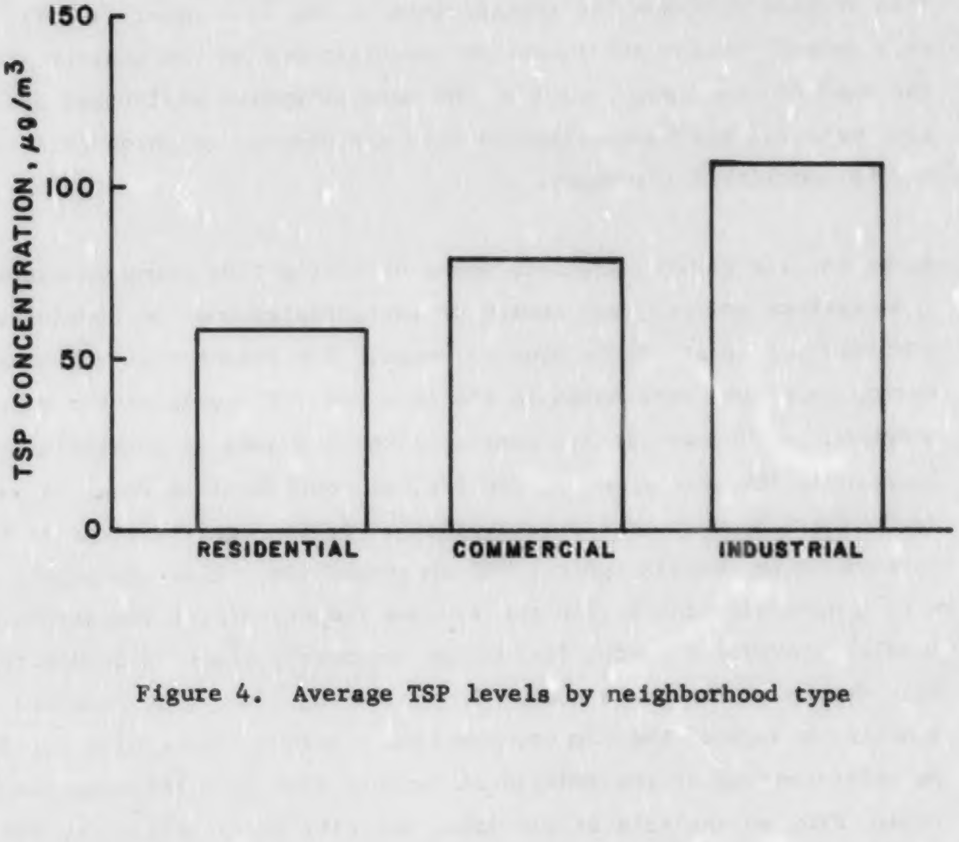


Figure 4. Average TSP levels by neighborhood type

concentrations at all the sites in the 14 study cities varied by the primary neighborhood classification of residential, commercial, and industrial. Residential neighborhoods generally had TSP concentrations in the range of 50 to 70 $\mu g/m^3$; monitors at commercial sites recorded a wider range of values, principally between 60 and 110 $\mu g/m^3$; and industrial neighborhoods had the highest TSP levels, averaging between 80 and 150 $\mu g/m^3$.

To explain not only why these TSP levels are what they are but also why they vary as they do, the analyses conducted in this study drew upon the general findings from the city studies discussed in Section II. These findings identified major topics of concern for assessment of the TSP standards attainment problem on a nationwide basis: large scale considerations, traditional sources, nontraditional sources, monitoring considerations, and meteorology/climatology. This categorization structures the following discussion, which summarizes the findings of the cross-city analyses presented in the appendices.

BACKGROUND AND LARGE-SCALE CONSIDERATIONS

In reviewing the literature, and in considering the wide range of typical air quality levels over different parts of the country, it is apparent that there is a significant portion of TSP levels that varies over a geographical scale much larger than any one or even a few AQCRs. On an overall average basis, the levels of TSP measured in nonurban areas represent the concentration of particulates in the air masses before they arrive in an urban area; hence the wide range of nonurban values implies that comparable cities, located in different portions of the country, would require different degrees of control to attain and maintain the ambient standards. Therefore, quantitative air quality planning requires an understanding of these levels and how and why they occur.

Terminology

Variously, particulates either measured in or presumed to originate in nonurban areas beyond the jurisdiction of local or state agencies have previously been labelled in one way or another under the heading "background." The usage of the term, however, when examined carefully, is found to entail a number of somewhat different concepts. The official concept of background is defined in the Requirements for Preparation, Adoption, and Submittal of Implementation Plans (40 CFR 51.13):

> For purposes of developing a control strategy, background concentration shall be taken into consideration with respect to particulate matter. As used in this subpart, 'background concentration' is that portion of the measured ambient levels of particulate matter that cannot be reduced by controlling emissions from manmade sources; 'background concentration' shall be determined by reference to measured ambient levels of particulate matter in nonurban areas.

Unfortunately, this definition reflects to some extent the prevalent variation in usage of the word "background," and hence contradictory usage of the term continues. Under the first part of the last sentence, in which background is defined as the uncontrollable portion of TSP, EPA regulations provide for rollback calculations to ascertain the degree of emission control necessary for the attainment of the air quality standards. The rollback formula:

$$\text{reduction required} = \frac{\text{ambient - standard}}{\text{ambient - background}}$$

tacitly assumes that the background level is a lower limit below which the ambient concentration cannot be reduced. On the other hand, in air quality modeling efforts, the background is frequently defined as the difference between the measured concentrations and the calculated concentrations which includes into background any source not included in the inventory used. In still other circumstances, an agency may choose to regard as "background" any TSP coming across the boundary into their jurisdiction, regardless of whether that jurisdiction extends appropriately into nonurban areas.

Contradiction in the usage of the term background also arises from the latter part of the above citation referring to the actual measurement of background. Following that concept, the background levels most often used in air quality reflect measurements of the ambient air quality in some remote rural area; this may possibly be within the county, AQCR, or state, depending upon the jurisdiction of the planning agency; or may be very far away. Where possible, these measurements are made upwind of the prevailing flow of air so as not to sample the particulate contribution of the area. However, what these remote monitors are actually measuring is not necessarily an uncontrollable or nonmanmade level of TSP. Rather, these measurements simply reflect the particulate concentrations coming into the urban area, including not only the natural, uncontrollable particulates but also man's contribution to the nonurban particulate levels; these latter include emissions in rural areas, particles transported from distant urban areas, and secondary particulates.

To avoid confusion with previous use of the term background, the term nonurban particulate will be used in this report to refer to the latter part of the EPA definition presented above; i.e., the TSP concentration determined by measuring the ambient levels of particulate matter in nonurban areas. The major components of nonurban particulates are listed below:

- Natural particulate — TSP contributed solely by natural processes and thus truly uncontrollable; includes a global contribution, which includes both primary and secondary particles, and a continental contribution, primarily from wind erosion of soil.

- Transported particulate — TSP levels that arise due to emissions from man's activities in "upwind" urban and industrial areas; includes both primary and secondary particulates transported from one area to another.

- Local influences — TSP measured at nonurban monitors that is contributed by emissions in rural areas (dirt roads, agricultural tilling, space heating, rural industrial sources) and affected by the actual placement of the monitor (reentrained dust, small town activity).

Because the term background has also connoted TSP that cannot be explained through modeling efforts and TSP that cannot be controlled through control of primary particulate sources, the excess of secondary particulates measured in urban areas over the levels measured in nonurban areas will also be considered under this topic.

Natural Particulates

The emission and formation of particulates from natural sources result in low concentrations of ambient particulates that have always existed, regardless of man's influence. The most important of the natural sources of particulates are soil and rock debris, forest fires, plants, volcanoes and ocean salt spray; in addition, natural sources can emit gaseous pollutants which can react to form particulates. As shown by the estimates in Table 8, particulate emissions from natural sources and particulate formation from naturally occurring precursors far outweigh the contribution of man-made sources on a global scale; however, man-made emissions are more important for standards attainment because they are gathered into small areas.

Table 8. ESTIMATES OF PARTICLES SMALLER THAN 20 μm RADIUS EMITTED INTO OR FORMED IN THE ATMOSPHERE (10^6 metric tons/year)[1]

Man-made	185 - 415	
Particles from direct emissions		10 - 90
Particles formed from gaseous emissions		
Sulfate from SO_2		130 - 200
Nitrate from NO_x		30 - 35
Organics from hydrocarbons		15 - 90
Natural	773 - 2200	
Soil and rock debris (wind erosion)		100 - 500
Forest fires and slash-burning debris		3 - 150
Sea salt		300
Volcanic debris		25 - 150
Particles formed from gaseous emissions		
Sulfate from H_2S		130 - 200
Ammonium salts from NH_3		80 - 270
Nitrate from NO_x		60 - 430
Organics from hydrocarbons		75 - 200
Total	958 - 2615	

Of the natural sources of particulate emissions, sea salt is probably the largest emission source, but its greatest effect on TSP concentration occurs over the oceans; its contribution to TSP levels extends over land only a short distance. Over land, wind-entrained soil dust is the largest direct source of particulate emissions. Gaseous emissions from natural sources are scavenged through various chemical reactions and result in the production of significant quantities of aerosol materials over a broad area. Volcanic emissions can vary greatly from year to year but usually do not contribute a large proportion of the natural particulate emissions. The contribution of forest fires can only be estimated roughly at present; though it appears small in Table 8, it may be considerably more important with respect to air quality since such fires are frequently adjacent to urban areas. Pollens, spores, and bacteria are an insignificant fraction of the total emissions.

The primary distinction between the sources of natural particulates with respect to TSP levels is simply their location and to some extent the effective emission height and particle size. Generally, the natural particulate levels can be thought of as contributions from two types of sources: global sources and continental sources. Global particulates arise from the heated emissions from volcanoes and, to a lesser extent, forest fires, and from secondary particulates formed from natural gaseous emissions; these emissions are characteristically in the submicron range. Sea salt is also often referred to as a global particulate. Continental sources are wind erosion of rocks and soil; pollens and spores; and (overlapping global particulates) forest fires and secondary particulates, especially hydrocarbons from plant exudations.

The contribution from global sources is considered relatively constant across the North American continent in the range of 1 to 5 $\mu g/m^3$; for TSP strategy planning, the contribution from continental sources is much more important than that from global sources. Continental particulate levels are much higher and they vary across the continent. For example, in the Great Plains region of the United States, wind erosion of soil is estimated to produce a larger mass of particulates than other sources in the region and can result in high dust concentrations over large areas. Most duststorms occur in the spring but air pollution from duststorms can be a problem in other seasons as well. The rainfall and soil erosiveness of an area are also influential with respect to the frequency and severity of duststorms.

Transported Particulates

The term transport refers to the movement of particulates over a greater distance than normally considered for dispersion modeling used for air quality planning. Transported particulates include primary particles, which are emitted directly into the air and secondary particles, which are formed from reactions of gases in the atmosphere. While natural particulates can also be transported considerable distances, this discussion of transported particulates is meant to center on particulates that originate from man's activities.

Transported Primary Particulates — The transport of primary particulates may be divided into two classes — short-range and long-range. Long-range transport occurs when the particulates are mixed into an air mass and travel several hundred kilometers or more without any removal mechanisms such as washout or rainout. This phenomenon of transport is directly related to meteorology because it requires a stable air mass moving across the country. An interesting case study of the transport of a particular air mass is described in Appendix C. This study demonstrates how long-range transport can produce abnormally high values of particulates over short periods, causing violations of the 24-hour standards. The degree to which it affects annual means is related to the frequency of such occurrences.

Short-range transport refers to the transport of particulates over less distance, ranging from a few to about 100 kilometers. It is primarily concerned with the movement of particulates across planning area boundaries; i.e., from the jurisdiction of one air pollution control agency into the jurisdiction of another.

Obviously, short-range transport of primary particulates is of principal concern in areas which have adjoining urban areas with insufficient rural areas between to allow for removal or dispersion of the pollutants. Such is the situation in the northeast where the air may sweep up past Baltimore, Washington, and Philadelphia into New York and up to Boston. In the study of Providence under this effort, high values of particulates, even in the less developed areas of the AQCR, were most often associated with winds from the direction of New York City. Meteorology is a complicating factor in this analysis because of variations in windspeed and rainfall with changing wind direction. However, it is likely that such conditions do exist.

Over even a smaller scale, transported primary particulates are important whenever air crosses from one region that is completely autonomous into another area that has separate control. Such a situation was found in Philadelphia in the course of this study. The Philadelphia Air Management Services has complete responsibility in Philadelphia County, while the Commonwealth of Pennsylvania Department of Environmental Resources has responsibility for the counties surrounding Philadelphia. Since the entire County of Philadelphia can be considered urbanized, the most remote site in the network is one located in a residential neighborhood near the border of Philadelphia and Montgomery Counties. This site had an annual mean of 59 $\mu g/m^3$ in 1974, implying that there were virtually no means of avoiding violating at least the secondary annual standard as the air passed over the city. Another site, in a more industrialized corner of the county but also near the industrialized areas of Delaware County in Pennsylvania and Gloucester County in New Jersey, had an annual mean of 94 $\mu g/m^3$. The value at this site is especially important since it is in the southwest corner of Philadelphia County, the direction from which most of the air crossing the county would come.

Transported Secondary Particulate — As mentioned previously, secondary particulates are the products of chemical reactions occurring in the atmosphere. They can initiate in the gas phase or as a result of reactions between gases and already existing particles. They are a major source of the ubiquitous Aitken nuclei, or homogenous nucleation centers, that are essential for most of the condensation processes that take place in the atmosphere. They are also a prime component of urban smog.

Composition — The main ingredients in the formation of secondary particulates are sunlight and gases such as sulfur dioxide, ammonia, nitric oxide, water vapor, and hydrocarbons, which enter the atmosphere from both natural and manmade sources. Secondary particulates range in size from molecular clusters with diameters on the order of 0.005 µm to particles with diameters as large as several micrometers. Field studies of urban aerosols[2-4] have shown that the highest concentration of secondary particulates is usually in the range 0.01 to 1.0 µm. The concentration of particles in this size range can vary directly with intensity of sunlight and concentration of ozone.

The principal factors governing distribution by size are the respective rates of particulate formation and removal. The smallest particles, which are created constantly during the daylight hours, coagulate into larger particles. The overall life cycle of secondary particulates is difficult to determine; estimates range from 1 week to 40 days.[5] In the end, the particles are either removed from the atmosphere by precipitation or dry deposition. During this period, however, they may be transported vast distances from the source of the gaseous precursors.

Found in both urban and rural areas, secondary particulates are in general composed of three types of chemical compounds — sulfates, organics, and nitrates — which are briefly discussed below.

Sulfates. Sulfates are ubiquitous. A large fraction of the global aerosol is ammonium sulfate $(NH_4)_2SO_4$. Sulfates such as sulfuric acid (H_2SO_4), which is found in most urban aerosols, result from the reaction of SO_3 and water. The sulfate salts, such as $PbSO_4$, in turn, derive from the reactions of compounds such as ammonia or metallic oxides with sulfuric acid droplets.

Organics. The second major constituent of secondary particulates is produced by the reaction of hydrocarbons with oxidants (e.g., NO_2, O_3) in the atmosphere to produce peroxide radicals. Through a series of chain reactions, these radicals eventually form large organic molecules which condense to form droplets or solid particles.

Primary sources of hydrocarbons in urban areas are automobile exhaust and industrial effluents. In some rural areas, hydrocarbon emissions from natural sources may be significant.

Nitrates. Nitrogen oxides emitted into the air can be oxidized and react with water to form nitric acid in either vapor or droplet form. From this form, nitrates are created through reactions with gaseous or solid species.

Air quality impact — Secondary particulates can occur both over a long period of transport and apparently also fairly quickly in an urban area. As with primary particulates, secondary particulates can be important over both short-range and long-range transport. The long-range transport study in Appendix C found sulfate levels three times higher than normal; shorter transport of secondary particulates is known to contribute to high levels in the northeast.

Annual levels of sulfates and nitrates for nonurban areas near each of the 14 study cities are given in Table 9 along with the estimated total nonurban levels. Average values for each of the industrialization classifications for the cities in the east (of the Mississippi River) versus the west, and for the cities in the north (heating degree days more than 4000/year) versus the south, have been calculated. While the heavily industrialized cities have the highest nonurban levels of secondary particulates, this division apparently results from the geographic location of the cities. The highest levels within each category of industrialization occur in cities east of the Mississippi, where the density of industrialization

Table 9. NONURBAN LEVELS IN THE 14 STUDY CITIES[a]

	Nonurban levels, $\mu g/m^3$		
Cities	SO_4	NO_3	Total
Heavily industrialized			
Cleveland	10	1	30
Birmingham	7	1	30
Philadelphia	10	1	35
Baltimore	8	1	35
St. Louis	6	1	25
Cincinnati	11	1	35
Average	8.7	1.0	31.7
Moderately industrialized			
Chattanooga	6	2	35
Denver	2	0	20
Seattle	3	0	15
Providence	7	1	30
Average	4.5	0.8	25.0
Lightly industrialized			
Washington, D.C.	8	1	30
Oklahoma City	3	1	25
Miami	5	1	25
San Francisco	2	0	15
Average	4.5	0.76	23.8
East	8	1.11	27.8
West	3.2	0.4	20.0
North	7.2	0.78	28.3
South	4.6	1.0	26.0

[a] Best estimate averages based upon composite values of available NASN data.

is greatest, and also in the northern cities, where space heating is more important. In the two dichotomous breakdowns - north versus south, east versus west - the impact of geographic location on the nonurban values is obvious. A logical extrapolation of these data would be that nonurban secondary particulates are highest in the northeast and lowest in the southwest; such findings have been noted in other studies.[6]

Other Factors

As mentioned previously, two other factors are important when considering nonurban TSP levels and the use of such levels in air quality planning. Nonurban levels can reflect local influences that are not of concern when planning control strategies for an urban area because the particulate matter is not actually carried into the urban area. At the same time, secondary particulates formed locally in an urban area are not accounted for in nonurban monitoring, and therefore, these urban secondary excess levels are not appropriately incorporated in traditional air quality planning.

Local Rural Influences - Local influences on nonurban levels can be traditional emissions such as from local space heating and rural industrial activity; but, more likely, these local influences are artifacts of the monitor placement so that the TSP levels are subject to reentrainment from dirt roads, agricultural tilling, or natural wind erosion. Similarly, TSP levels reported as nonurban levels may be from monitors located in small, rural towns; these monitors would also be measuring the particulates generated by man's activities (traditional and nontraditional sources) in the town.

Emissions from dirt roads in the major counties in the study AQCRs are discussed later under the topic of Nontraditional Sources. That analysis suggests that the current inventories for dirt roads provides an exaggerated picture of the importance of unpaved rural roads to the air quality in an urban area. The current inventories suggest that emission levels due to dirt roads in urban counties are usually much higher than the total traditional source emission levels in urban areas. Obviously the air quality impact from these sources is not equivalent to that from traditional sources; otherwise, the TSP concentrations in rural areas would be expected to reach or exceed those in urban areas.

Similar findings apply to the inventoried emissions for agricultural tillings. While the emissions from tilling were never as great as those from dirt roads in the 14 AQCR's studied, in some areas the levels are quite high; e.g., in the San Francisco Bay Area AQCR, emissions due to tilling are inventoried at almost 190,000 tons per year. Since tilling does not occur throughout the year but only at certain seasons, any impact from tilling would be expected to be short-term, perhaps causing elevated levels for a month at a time.

Urban Secondary Excess - Secondary particulates formed in the urban area as a result of local emission sources have been ignored in control strategies applied to air quality planning; i.e., control of TSP concentrations has been approached solely by reducing directly emitted particulates. Presumably, the amount of secondary particulate formed is related to the amount of precursors, so that higher levels of secondary particulates may be expected to be found in the more industrialized regions. For sulfates, the amount of space heating with fuels high in sulfur may be important in winter.

Because of the different control approaches that are open to an individual air pollution control agency, it is helpful to separate out the secondary particulates formed within the jurisdiction of the agency from those formed in transport to the region. The annual levels of sulfates and nitrates for urban and nonurban areas in each of the 14 study cities are given in Table 10 and averages have been calculated for the same breakdowns given in Table 9. The data in Table 10 demonstrate that air entering the city is the predominant factor in determining the sulfate levels in a city but that nitrate levels can increase by a factor of three in the city. Since

Table 10. COMPARISON OF URBAN AND NONURBAN LEVELS OF SULFATES AND NITRATES IN THE 14 STUDY CITIES[a]

Cities	Urban levels			Nonurban levels			Urban excess		
	SO_4	NO_3	Total	SO_4	NO_3	Total	SO_4	NO_3	Total
Heavily industrialized									
Cleveland	10	3	13	10	1	11	0	2	2
Birmingham	14	3	17	7	1	8	7	2	9
Philadelphia	14	4	18	10	1	11	4	3	7
Baltimore	10	3	13	8	1	9	2	2	4
St. Louis	12	3	15	6	1	7	6	2	8
Average	12	3.2	15.2	8.2	1	9.2	3.8	2.2	6.0
Moderately industrialized									
Cincinnati	12	3	15	11	1	12	1	2	3
Chattanooga	11	2	13	6	2	8	5	0	5
Denver	5	3	8	2	0	2	3	3	6
Seattle	7	2	9	3	0	3	4	2	6
Providence	9	2	11	7	1	8	2	1	3
Average	8.8	2.4	11.2	5.8	0.8	6.6	3	1.6	4.6
Lightly industrialized									
Washington, D.C.	12	3	15	8	1	9	4	2	6
Oklahoma City	3	2	5	3	1	4	0	1	1
Miami	5	1	6	5	1	6	0	0	0
San Francisco	5	2	7	2	0	2	3	2	5
Average	6.25	2	8.25	4.5	0.76	5.25	1.75	1.25	3.0
East	10.78	2.67	13.44	8	1.11	9.11	2.78	1.56	4.33
West	6.4	2.4	8.8	3.2	0.4	3.6	3.2	2.0	5.2
North	10.1	2.89	13.0	7.2	0.78	8.0	2.89	2.11	5.0
South	7.6	2.0	9.6	4.6	1.0	5.6	3.0	1.0	4.0

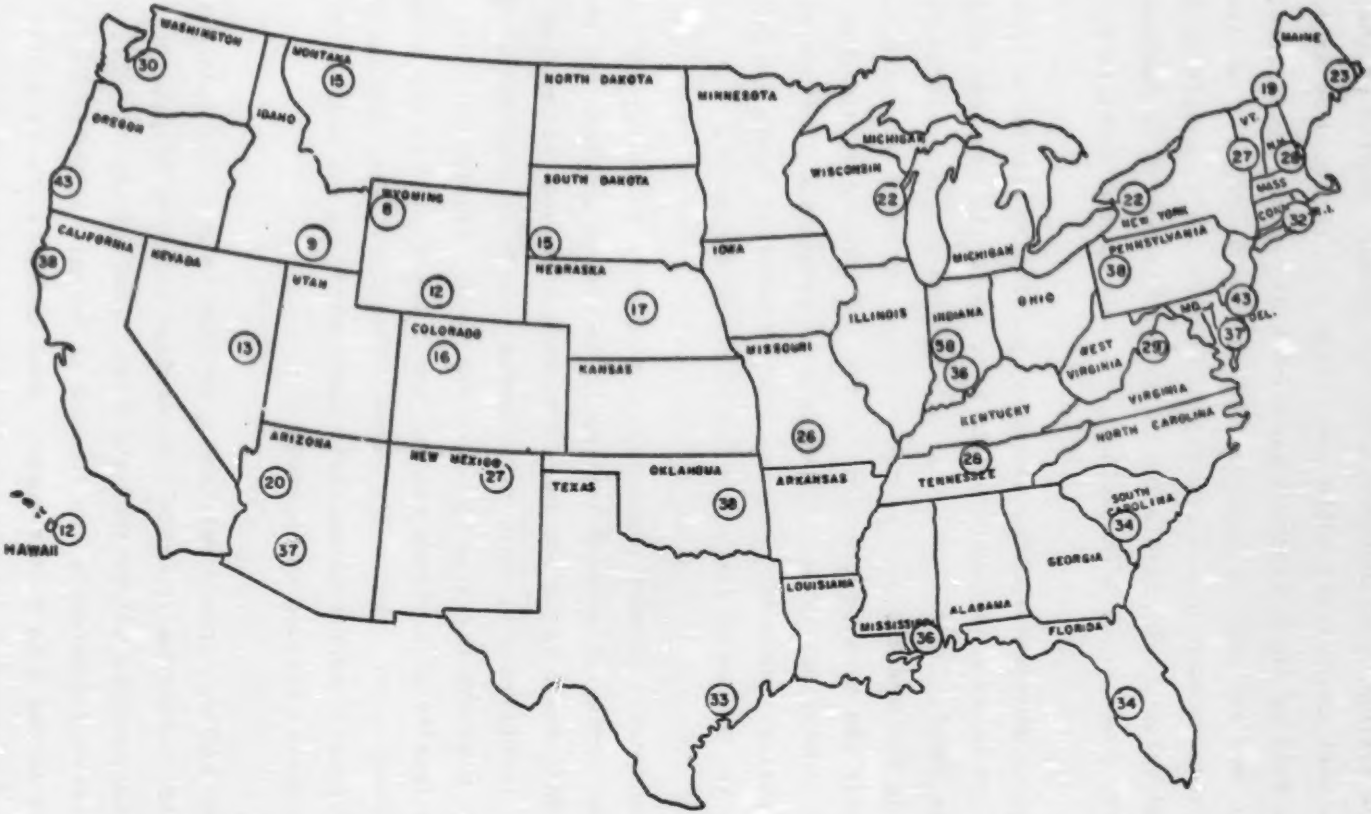
[a] Best estimate averages based upon composite values of available NASN data

sulfates are the predominant secondary pollutant, the average increase in secondary particulates is on the order of 60 to 70 percent. As may be expected, the largest increases (urban excesses) are seen in the highly industrialized areas where secondary particulate levels inside the city average 6 $\mu g/m^3$ above those in the nonurban setting; lightly industrialized areas have half of this increase. On the whole, cities may have concentrations elevated 5 to 15 $\mu g/m^3$ due solely to sulfates and nitrates. Two important points concerning Tables 9 and 10 are that some sulfates may be directly emitted as primary particulate. and secondary organics may also be significant, but adequate measurements were not available.

National Assessment

As has been shown above, particulate levels exist which are beyond the control of individual state and local air pollution control agencies. These levels of TSP enter the jurisdiction of an agency along with the air mass that is carrying them. The particulates entering a region may be the result of a facility a few miles upwind of the jurisdiction, of another city 50 km away, of sources generating precursors to secondary pollutants hundreds of miles from the region, or of natural nonurban sources such as sea salt, pollen, and wind-driven dust. While the smaller scale transport problems may often be adequately handled by cooperation between adjoining state and local agencies or by EPA regional office intervention, the larger scale influences either cannot be controlled or need direction and planning on the national level. These larger scale problems are addressed below.

The concentration of particulates in rural areas of the country has been monitored for many years as part of the National Air Surveillance Network (NASN). Figure 5 presents composites of values reported at various nonurban NASN sites from 1970 through 1973. The data in this figure indicate the wide range of annual means being reported. In addition to the problem of transported primary and secondary particulates, some of the range in TSP values is expected to be due to inconsistent and, in some cases, poor


WASHINGTON
30
OREGON
43
CALIFORNIA
38
IDAHO
NEVADA
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MONTANA
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UTAH
9
WYOMING
8
12
COLORADO
16
ARIZONA
20
37
NEW MEXICO
27
HAWAII
12
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
15
17
KANSAS
OKLAHOMA
38
TEXAS
33
MINNESOTA
IOWA
MISSOURI
26
ARKANSAS
LOUISIANA
WISCONSIN
22
MICHIGAN
ILLINOIS
INDIANA
58
36
KENTUCKY
TENNESSEE
28
MISSISSIPPI
36
ALABAMA
OHIO
WEST VIRGINIA
29
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
34
GEORGIA
FLORIDA
34
NEW YORK
22
PENNSYLVANIA
38
MD.
43
DEL.
37
VT.
27
N.H.
28
MAINE
19
23
MASS
CONN
32
R.I.

Figure 5. Composite annual geometric mean TSP levels at nonurban NASN sites from 1970 through 1973 ($\mu g/m^3$)

monitor siting. For instance, the high values reported at the monitors on the west coast (California and Oregon), which would be expected to have values half of those reported based upon global and continental particulate levels, are recorded by monitors located on the ground. As discussed later under reentrainment, such low siting is expected to result in highly exaggerated values. The high value of 58 $\mu g/m^3$ reported in Indiana is due to a nearby power plant influencing the levels in the rural area.

The impact that transported secondary particulates have on these nonurban sites can be seen in Figure 6, which presents the nonurban sulfate and nitrate levels for 1974. Almost no nitrates and very little sulfates are found in the western part of the country, yet secondary particulates consistently add more than 5 $\mu g/m^3$ to the TSP loading at nonurban sites east of the Mississippi River. These data reiterate the findings of the 14 city case studies: secondary particulates in nonurban areas can add significantly to the TSP burden on cities in the east and northeast.

The transported primary particulates cannot be so easily addressed on the national scale for several reasons. One reason is that the density of nonurban NASN monitors is too low to provide adequate information on the change of TSP levels between major urban areas. Such an analysis would have to include monitors operated by state and local agencies in order to be close to the density of monitors needed, and these data were not available on a nationwide or even regionwide basis. Therefore, the conclusions on transported primary particulates must stand solely on the earlier discussion and the analysis provided in Appendix C.

Another problem already mentioned, monitor height, not only means that transport cannot be accurately determined but also brings many of the reported nonurban values into question. Most of the monitors in the nonurban network apparently are located at heights below 10 feet, with many of them in the 3 to 6 foot range. Such monitors are as likely to be influenced by nearby disturbances as by any particulates being transported into the region.

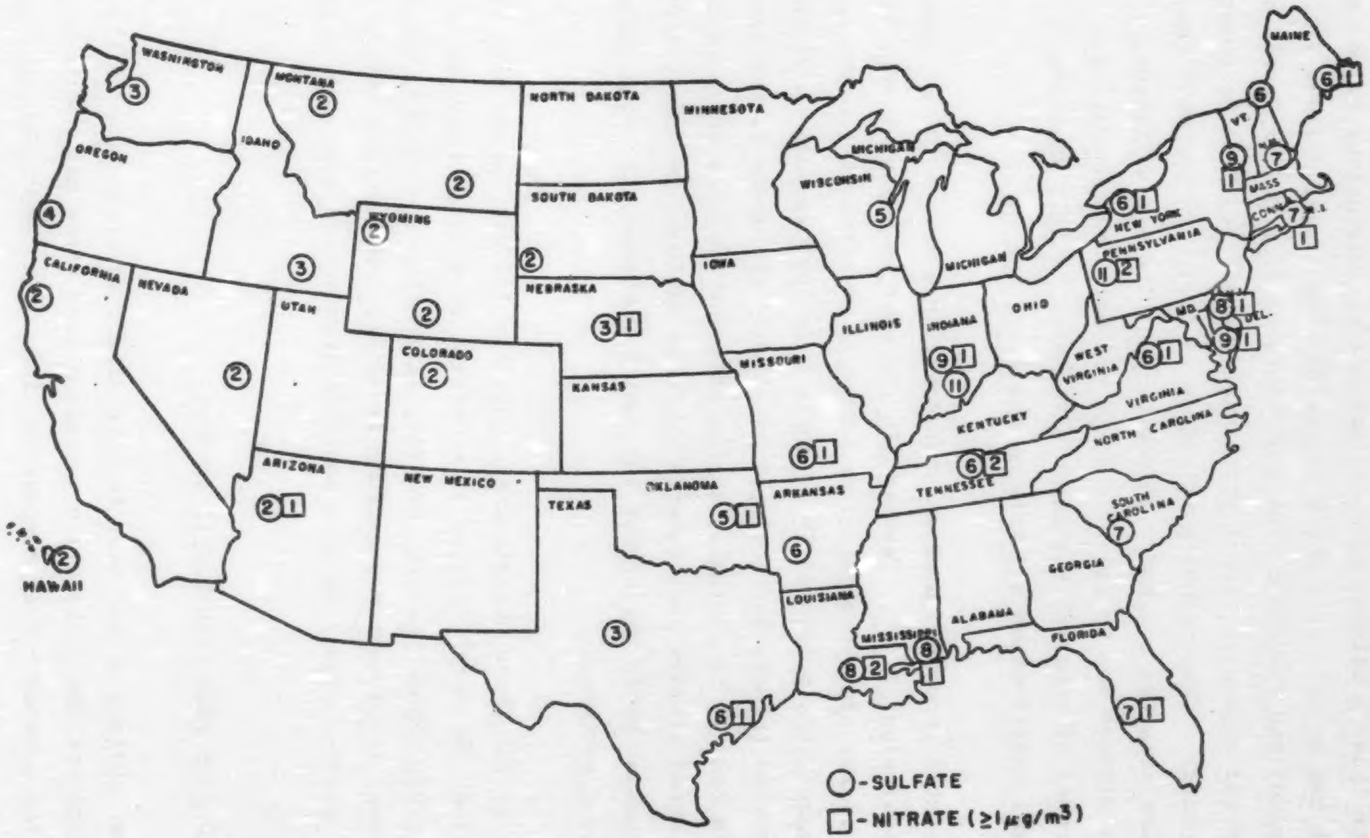
WASHINGTON
MONTANA
OREGON
IDAHO
NORTH DAKOTA
MINNESOTA
WYOMING
SOUTH DAKOTA
WISCONSIN
MICHIGAN
CALIFORNIA
NEVADA
UTAH
NEBRASKA
IOWA
COLORADO
KANSAS
MISSOURI
ILLINOIS
INDIANA
OHIO
ARIZONA
NEW MEXICO
TEXAS
OKLAHOMA
ARKANSAS
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
TENNESSEE
KENTUCKY
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
PENNSYLVANIA
NEW YORK
MD.
DEL.
VT.
N.H.
MASS
CONN
R.I.
MAINE
HAWAII
○-SULFATE
□-NITRATE (≥1μg/m³)

Figure 6. Annual geometric mean sulfate and nitrate levels at nonurban NASN sites – 1974

Despite these problems, some estimate of the variations in the nonurban levels can be made from the findings of this study. Figure 7 provides a conceptualized diagram of the contributions to nonurban levels as one moves across the country. Global particulates are assumed to be constant across the country. Continental particulate is lowest on the west coast, where the land area has not had a chance to contribute significantly, and highest in the midwest due to the high winds and more arid conditions. The occurrence of some off-the-ocean air masses is felt to bring down the continental contribution a little in the east.

Transported secondary particulates contribute only a few micrograms west of the Mississippi River. However, in the east, nonurban levels of secondary particulates are averaging around 10 $\mu g/m^3$. Although the long-range transport case study presented in Appendix C is for Oklahoma City, the impact of transported primary particulates on annual TSP levels in the west and midwest is felt to be minimal. In the east where cities are more concentrated, transported primary particulates are more serious, averaging about 5 $\mu g/m^3$ on an annual basis throughout the east but potentially much higher in the congested northeast.

On top of all these contributions, another few micrograms have been added to reflect the local influences occurring on a large scale basis in the rural areas (space heating, traffic, agricultural activity, etc.). This additional level does not include immediate impacts from nearby sources (power plants, roads) or from possible reentrained dust due to low monitor height.

PARTICULATES FROM TRADITIONAL SOURCES

The most obvious of the many factors affecting attainment of the TSP standards are the particulate emissions from three major categories of pollution sources — fuel combustion, industrial processes, and solid waste disposal operations. These three source categories have long been considered significant pollution problems, and have traditionally been the

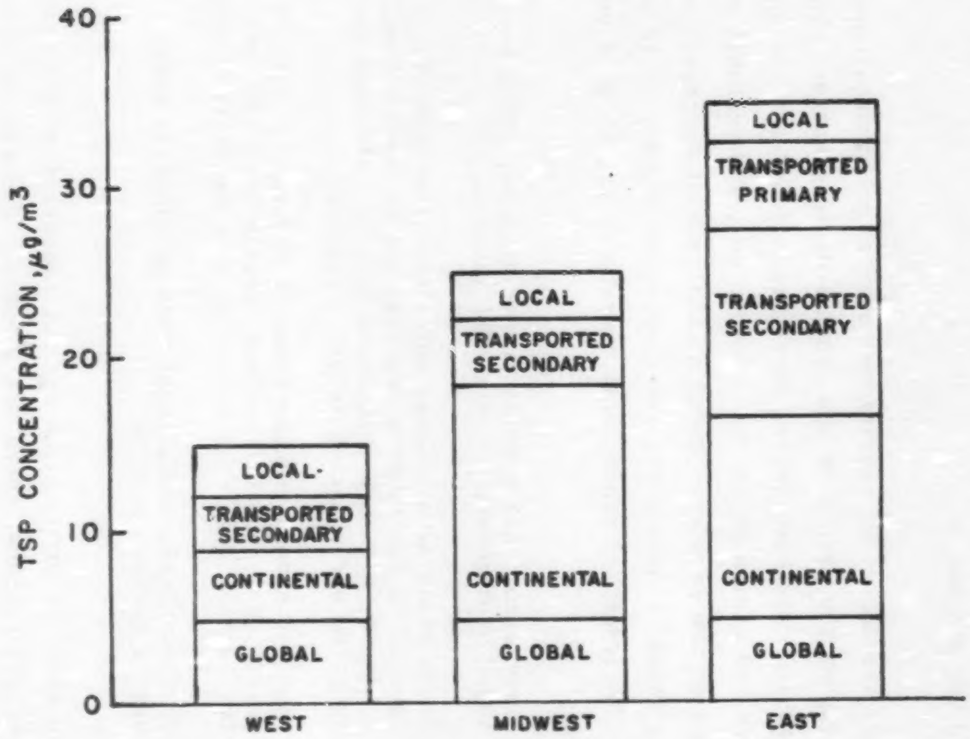

Figure 7. Average estimated contributions to nonurban levels in the East, Midwest, West

primary concern of air pollution control efforts; consequently, they have been labeled "traditional sources" for purposes of this study. This section summarizes the assessment made of the significance of traditional source emissions as a factor in the nonattainment of the TSP standards; Appendix D presents summaries of the data assembled and the analyses made to develop the assessment.

In general, the impact of traditional sources on nonattainment depends very heavily on the nature of the urban area in question. The 14 case study areas included both cities where traditional sources totally dominate the picture and cities where they are not now, and probably never were, a major share of the problem. Based on analysis of aggregate emission inventories, emission densities, and compliance trends, it is possible to summarize the impact of traditional sources in the 14 case study areas as follows:

I. Three areas, all heavily industrialized, still have a major problem with traditional sources;

II. Three areas have reduced emissions from traditional sources to the point where they are no longer totally dominant, although continuing further reduction and on-going surveillance is still required;

III. Four areas have reduced formerly moderate levels of traditional source emissions (mostly from fuel use for heating and light industry) to near insignificance;

IV. In four areas, traditional sources probably never were a serious problem.

While these specific proportions are not necessarily reflected in the overall national picture, there are certainly a number of urban areas throughout the country in each of these categories.

A comparison was also made of the emission parameters leading to this classification with air quality levels in the various urban areas, expressed as city wide average TSP concentrations. With adjustments made for differing nonurban levels and secondary particulates, essentially no difference in typical air quality between the third and fourth categories listed above was indicated, with the average for both groups being 35 $\mu g/m^3$ above nonurban levels (Denver was excluded as an anomaly). This approximates the contribution of nontraditional sources as discussed later. The three heavily-industrialized cities still dominated by traditional source emissions (Category I) had an average city wide TSP level of 66 $\mu g/m^3$ above nonurban, suggesting that about 30 $\mu g/m^3$ is the maximum potential city wide reduction, even with very stringent traditional source control. The three cities (Category II) that have made significant but as yet incomplete traditional source reductions averaged 48 $\mu g/m^3$ above nonurban levels, suggesting that there is still 10 to 15 $\mu g/m^3$ of traditional source influence on city wide averages which could be reduced somewhat with further control of traditional sources. Figure 8 displays the relationship between emission density and air quality, and illustrates the clustering of the study cities into the categories. It is important to remind the reader that these results must be interpreted as only semi-quantitative and extrapolated with care. Although it is believed they provide a good national aggregate assessment of the role of traditional sources, this analysis does average over different neighborhoods and over vastly different cities with significaly different sources and control programs, and meteorology.

With respect to the three major categories of traditional sources - fuel combustion, industrial processes, and solid waste disposal - the relative contributions also varied significantly with the nature of the different urban areas. The fuel combustion contribution to inventoried emissions ranged from less than 20 percent in clean-fuel, industrialized areas to well over 90 percent in totally nonindustrial areas, with industrial processes accounting for most of the balance. Solid waste disposal emissions were generally less than 5 percent.

Fuel Combustion

The magnitude of fuel combustion emissions depends primarily on the amounts and types of fuels burned, but the degree to which they are or can be controlled primarily depends on the installation size — point sources and

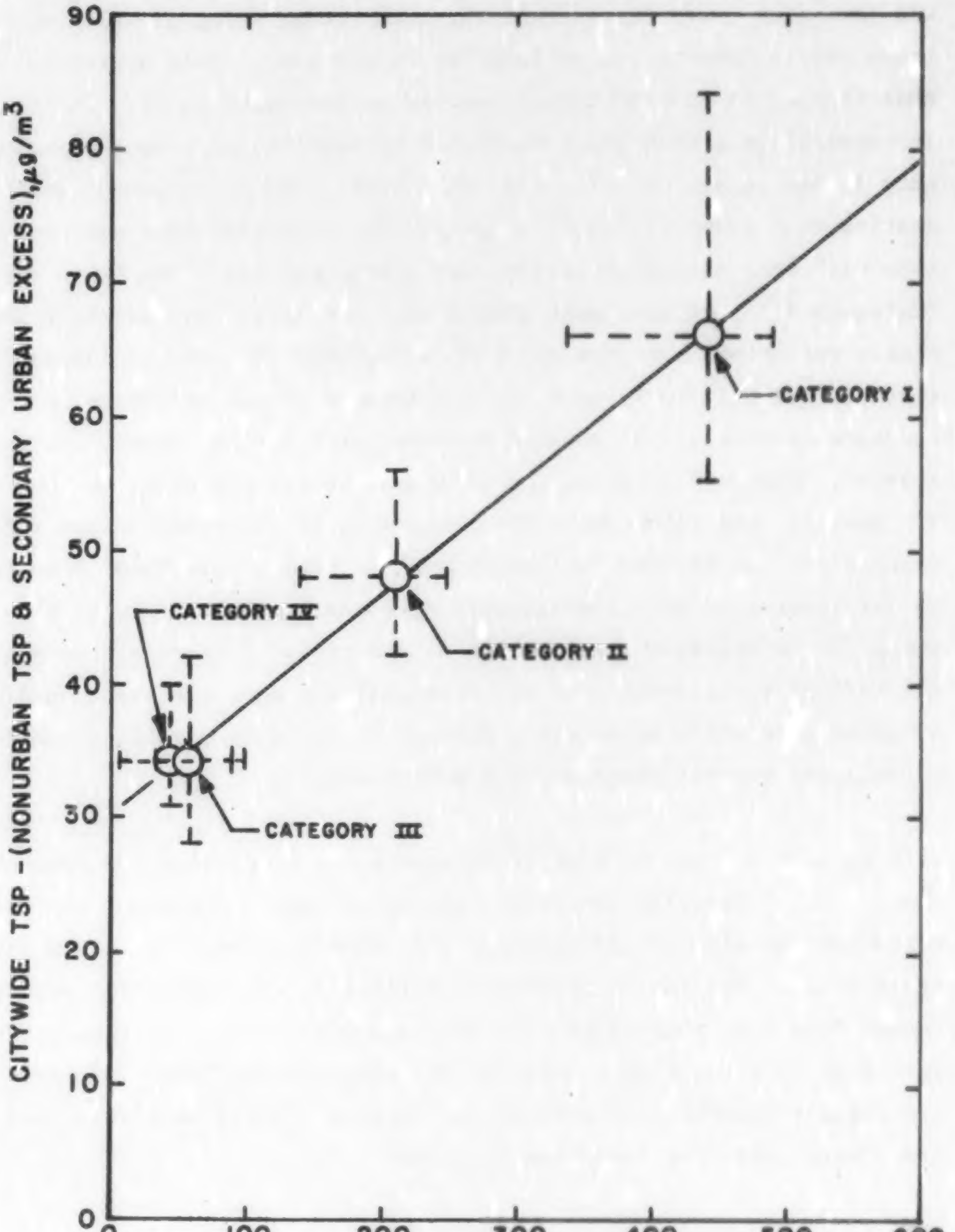

Figure 8. Relationship between city wide average TSP levels and traditional source emission density

area sources - and sometimes on the type of source - electric power, industrial or residential. The overall pattern of the fuel combustion emissions was generally as would be expected, with greater emissions in areas where coal and heavy oil are more prevalent, and in areas where major electric power or industrial combustion sources remain uncontrolled. Substantial further reductions in particulates from these sources are expected under present regulatory plans. However, if sources are required to continue burning coal or are switched back to coal, these reductions may not take place. There is a significant range in the stringency of emission regulations applied to combustion sources, so that in many areas there is room for further reductions by tightening the standards regardless of the fuel being used.

One particular aspect of fuel combustion emissions control to which the study sought an answer is the question of residential space heating. The use of coal in residential units has declined almost to the point of insignificance, but in coastal cities the use of oil (rather than gas) is common, and is likely to remain so. Since small oil burners are generally controlled only through visible emissions enforcement, if at all, the degree to which they might contribute to the TSP problem is an important open question. In the cities selected for the study, it proved impossible to separate the extensive residential use of oil from other fuel use and industrial sources by means of the air quality and emission data analysis techniques primarily used. However, it did prove possible to make a rough estimate of the impact from heating oil based on the microscopic analysis of hi-vol filters from the various cities. Composited results for each city, while subject to significant caution in interpretation, did indicate elevated levels of oil soot in those cities — Providence, Washington, Seattle, and Baltimore — where they would logically be expected. An approximate comparison of these results with those in the other cities suggests a contribution to TSP levels of 5 to 10 $\mu g/m^3$. This is not a small portion of the typical urban levels of 75 to 100 $\mu g/m^3$; it is a significantly larger portion of the 30 to 35 $\mu g/m^3$ "working range" between typical nonurban levels and the secondary standard.

Industrial Processes

The second major category of traditionally considered pollution sources are industrial process losses, as distinguished from emissions from industrial fuel combustion emissions. Process emissions are divided into stack emissions and fugitive emissions, the latter being those indirect emissions from doors, windows, etc., material storage piles, or other outside activity on the plant property. Historically, primary concern has been directed at stack emissions, which are more easily identified, quantified, and controlled, and have, in the past, been the major sources of particulate emissions from industry.

Stack Emissions — The degree of the process emission problem is dependent on the industrialization of the area in question. In the heavy industrial cities where control of process sources is still being pursued, these sources, along with industrial fuel use, dominate the air pollution picture. In those industrial cities where emissions from process sources have been generally controlled, they tend to remain roughly half the total inventory. The process weight regulations concerning stack emissions from process losses are not amenable to significant tightening, and further reductions of inventoried emissions will generally need to come from enforcement of existing regulations, adoption of tighter regulations for specific types of sources, and control of fugitive emissions. The industry categories that continue to pose the greatest stack emissions problem are the primary metals and minerals processing industries.

Fugitive Emissions - Fugitive industrial emissions have been traditionally recognized, but only minor control efforts have been pursued to date. In many operations, especially where dry materials handling is prominent, emissions are generated in processes both inside and outside of plant facilities, but on plant property, which are either ignored or insufficiently controlled so that significant particulate emissions are generated. For industrial processes that operate outdoors, such as coke ovens and rock crushing operations at quarries, these pollutants are directly emitted to the ambient air. Even when such processes are enclosed, the pollutants emitted into the working environment may escape to the atmosphere through windows, doors, roof ventilators, or even unsealed cracks in walls. In either case, those pollutants that enter the outside ambient air have been defined as fugitive emissions.

Fugitive emissions result from a wide variety of circumstances, including poor operation or maintenance of process equipment. For example, fugitive emissions can be the result of leakage from warped doors on coke ovens as well as the oven charging operation itself. Storage piles and handling operations for sand and gravel, coal, grain, and other materials that are kept in the open can become fugitive sources when a strong wind blows over them. Similarly, dirt and gravel parking lots and roadways on industrial property can become major sources of particulates due to either wind erosion or traffic.

Fugitive emissions have generally been assumed to be small in comparison to stack emissions. However, with stack emissions coming under controls that may provide up to 99 percent reduction, the relative importance of fugitive emissions has been growing, and they may now comprise a significant portion of nationwide emissions. For example, EPA has estimated that total fugitive emissions of particulate from electric arc furnace charging can be 5 to 50 times the amount of the stack emissions emitted downstream of the control device.

Even if the quantity of fugitive emissions from a process is small in comparison with the stack emissions, the low height at which they are typically emitted means that very little dilution occurs and fairly high ambient levels are created. Consequently, even though adequate emission estimates are lacking, fugitive emissions appear to be a significant and increasing problem. A very rough estimate based on comparing TSP levels at various monitoring sites (see Appendix D) suggests their aggregate impact in industrial neighborhoods is typically on the order of 25 $\mu g/m^3$.

Reduction of fugitive emissions will likely require a new approach to regulatory control of such emissions. Currently, regulations for control of fugitive emissions are of three general types: nonspecific nuisance regulations, quantitative property-line regulations, and regulations that prescribe specific control measures in specific circumstances. The majority of regulations in the country are of the first type, defining dust as a nuisance and often requiring "reasonable precautions" to prevent emissions. While flexible and capable of being strong enforcement tools, such regulations have not in fact proven effective on an overall basis. The other two types can be more effective, though clearly not without serious enforcement efforts. Property-line regulations in particular require enforcement and measurement techniques that are even more difficult than those required for stack emission sources. Although both alternative types are apparently somewhat better than nuisance regulations, there were only limited areas where they are used, and no areas where an extensive, effective control effort was underway.

Solid Waste Disposal

Of the several methods of solid waste disposal, incineration and open burning have traditionally been the most common in urban areas and, therefore, the most significant sources of particulate emissions. Under pressure from pollution regulations, however, the larger point sources of solid waste disposal emissions, municipal incinerators and large industrial installations have been controlled or replaced, while the smaller residential and commercial incinerators and open burning in dumps are typically tightly regulated and often banned. With the continuing trend toward landfills, recycling, and the use of combustible rubbish as a fuel supplement, solid waste disposal is expected to continue to decline in significance as a factor in attaining the NAAQS.

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Surveillance, Compliance and Enforcement Programs

An integral part of the impact that emissions from traditional sources may have on standards attainment is involved with the nature and effectiveness of the pollution control effort applied to them. Since fuel combustion, industrial processes and solid waste disposal have long been viewed as important sources of particulate emissions, maintaining surveillance over these traditional sources and enforcing regulations concerning them have been major activities of many control agencies since their inception. The nature of the control programs varies significantly, involving various combinations of source registration, permit systems, inspections, and so on.

The achievements of surveillance and enforcement programs depend on the matching of enforcement activities to the nature of the particulate emission problem. Among the 14 cities, the largest actual reductions in emissions from traditional sources have been achieved in those cities where surveillance and enforcement programs are comprehensive and vigorous. The activities of such programs generally included the following: constant surveillance and patrols, frequent inspections of problem sources, a general knowledge of all of the traditional sources, rigorous compliance determination, prompt action when a violation or upset occurs, issuance of compliance orders that are strict yet reasonably attainable in the opinion of an appeals board, and strict enforcement of compliance schedules.

The stringency of the regulations being applied is obviously important in determining the reductions in particulate emissions actually obtained. Study findings indicate, however, that somewhat more important are the enforceability of the regulations, the strictness of the enforcement, and especially the manner in which compliance is determined. The enforceability of regulations affects the ease and speed with which emissions are controlled, and is influenced by the types of regulations in effect.

For example, in dealing with numerous small incinerators, a standard specifying certain types of equipment is much easier to enforce than an emission standard which requires monitoring; in dealing with coke ovens, an efficient standard is one that specifies maintenance and operating conditions; in dealing with fugitive emissions, a source-specific regulation is more effective than a general nuisance regulation. The enforceability of regulations is also related to the institutional channels through which any hearings and appeals proceed. Enforcement is more effective and more efficient when control activities and enforcement proceedings are conducted by the same governmental level — or at least by well-coordinated and geographically proximate agencies.

Another important concern is the matter of compliance determination. It is not at all clear that reports of full or near compliance actually mean that all or most traditional sources are in compliance with the regulations. While it was not a major purpose of the present study, some understanding of the methods used for compliance determination was obtained during discussions of overall compliance status. Only a few of the agencies conduct or require actual stack tests and then not on a routine basis. More commonly, compliance determination is done on the basis of walk-through inspections and theoretical calculations based on process loads, emission factors, control efficiency specifications, and similar data. While this type of compliance determination is appropriate for some sources and control measures when done by well-trained agency personnel, it is equally inappropriate for other, more complex sources with untried control technology, particularly when performed by relatively inexperienced agency personnel.

Air Quality Impact

A primary objective of the study was to develop an understanding of the impact that traditional sources have on TSP levels. Specifically, it is important to place traditional sources in a proper perspective with respect to the problem of standards attainment. The type of analysis based on citywide levels that was presented in Figure 8 is adequate for a broad, general perspective; however, a more careful analysis involving individual monitoring sites was also undertaken in order to provide a more detailed and comprehensive picture. This effort, involving over 150 hi-vol sites, considered in detail the nature of the site neighborhoods and the air quality levels recorded, and has provided an overall perspective which is used throughout this section to structure the summary discussion. Figure 9 indicates the quantitative impacts in various types of neighborhoods estimated to result from traditional source emissions. The figure estimates the impact at residential, commercial, and industrial sites in cities with two different levels of traditional source prominence, following the grouping presented in Figure 8. The higher portion of the bars represent the three cities where traditional sources are still dominant (Category I), and the lower portion the cities where significant control has taken place (Category II); in the other two categories, where traditional sources are largely absent or controlled, no apparent impact was seen except in the industrial area itself. With respect to other parameters, such as meteorology, the estimates should be viewed as representing a hypothetical average city. The traditional sources in a heavily industrialized, not yet controlled city add 10 $\mu g/m^3$ at a typical residential site, 20 $\mu g/m^3$ at a commerical site, and about 60 $\mu g/m^3$ at an industrial site. Roughly about 20 $\mu g/m^3$ of the latter may be attributed to fugitive sources.

PARTICULATES FROM NONTRADITIONAL SOURCES

The above discussion focused on sources traditionally considered for control of ambient levels of particulate matter; i.e., sources which are generally stationary point sources, or fugitive emissions. These traditional sources were shown to cause levels of TSP that were far in excess of the national ambient air quality standards. However, even in cities where TSP emissions from traditional sources are relatively small, citywide averages are 30 $\mu g/m^3$ or more above nonurban levels, and the secondary annual standard is being violated. Monitors in apparently clean

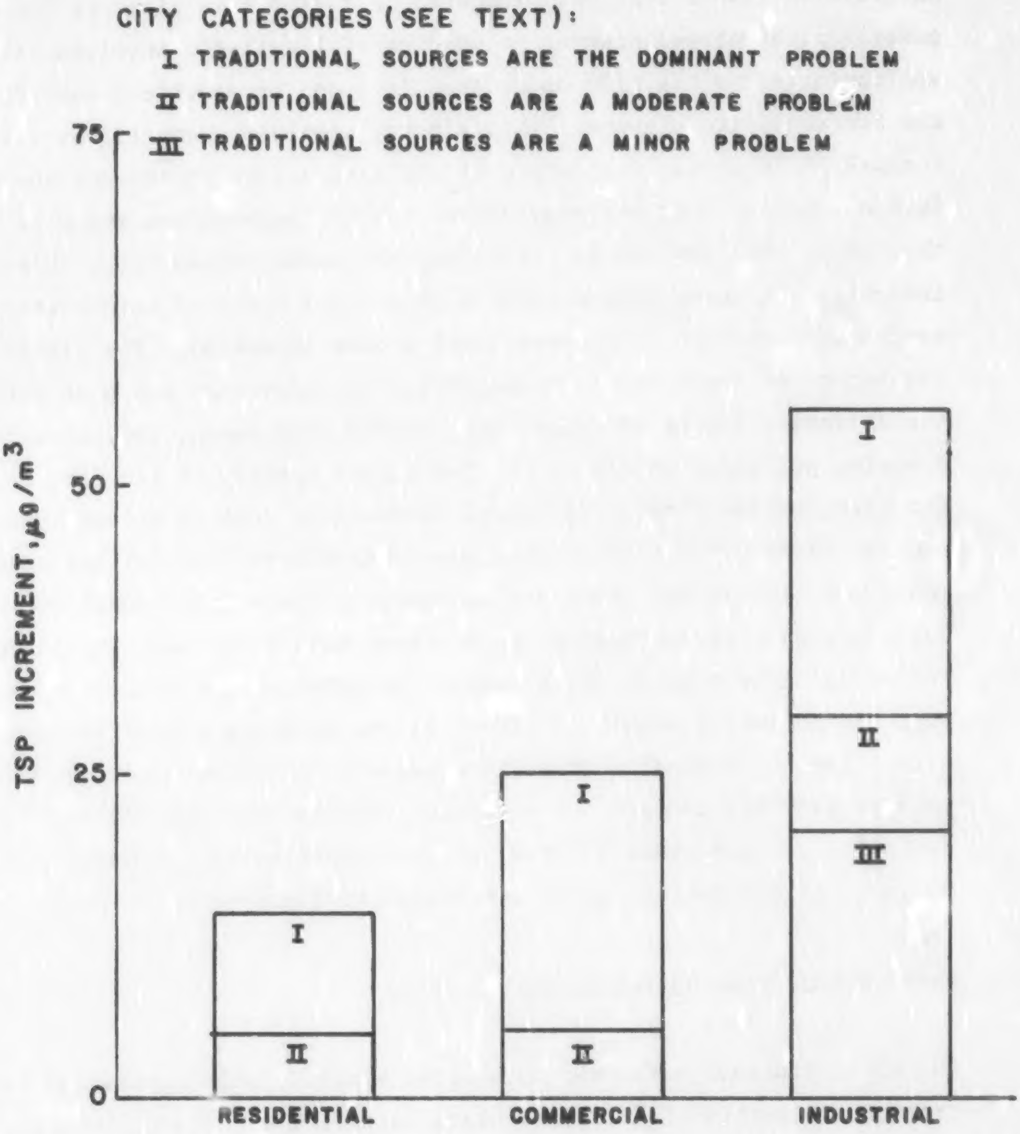


Figure 9. TSP increments due to traditional sources at different site types by city category

areas of a city or in smaller, nonindustrial cities have measured high TSP concentrations which cannot be explained by modeling with traditional source emissions or which fail to decrease as expected under controls of the State Implementation Plans. These findings indicate that a certain level of particulate in cities is caused by the concentrated activity in an urban area. These activities are here collectively designated "nontraditional" sources; i.e., those sources not traditionally considered in air pollution control strategies.

Nontraditional sources of particulates may be divided into two categories. One category consists of obvious, distinct sources of emissions that have not been normally considered as sources; these include construction and demolition activities, emissions from tailpipes, and tire wear. The other category refers to the more general problem of activity in the city and the characteristics of the urban setting that allow particulates to become entrained or reentrained.

Before the discussion of these categories, two terms merit differentiation: fugitive emissions and fugitive dust emissions. Both refer to general, nonstack emissions of particulates. However, fugitive emissions (included under traditional sources) result from industrial-related operations and escape to the atmosphere through windows, doors, and vents rather than through a primary exhaust system. Fugitive dust emissions, on the other hand, are generally related to natural or man-associated dusts (particulate only) that become airborne due to the forces of wind, man's activity, or both. Fugitive dust emissions include windblown particulate matter from paved and unpaved roads, tilled farm lands, and exposed surface areas at construction sites. Natural dusts that become airborne during dust storms are also included as fugitive dusts.

Estimates of emissions from nontraditional sources in several comprehensive reports tend to indicate that the total level of particulates from several of these activities are significantly larger than those from traditional sources. This study did not include any major effort to develop additional emission factors; rather, it concentrated on a review of the previously published literature plus analysis of air quality data collected to determine the impact of such sources on ambient TSP. Appendix E provides the detailed results of much of this analysis, the following discussion summarizes the findings.

Reentrained Particulates

In an urban area, particulate matter accumulates on the various city surfaces due to fallout, and especially heavy loads on streets can result from dirt and mud carryout from unpaved parking lots and roads, spillage from trucks, and sand and salt applied for snow control. This particulate matter can then become entrained and at least temporarily suspended in the ambient air due to wind erosion or man's activities disturbing the surface.

Natural Reentrainment - Natural reentrainment of particulates occurs when wind is strong enough to lift particulates from the surface. Due to the mechanics of wind erosion, such movement is more likely to be initiated in an urban area where hard, flat surfaces are exposed to the sweeping action of the wind. Based upon the analysis presented in Appendix F of this report and other literature, winds above 10 to 12 miles per hour are likely to be contributing to the TSP levels. Above this speed, the reentrained dust maintains the TSP level above what would be projected based upon the balanced dilution effect of the ventilation accompanying the wind. Cleaner surfaces (determined by comparisons after rainfall) did allow the dilution effect to reduce levels further than when the wind was blowing over dirtier surfaces (measured on days before which there was no rainfall).

Vehicular-induced Reentrainment - The most important contribution to reentrainment caused by man in an urban area is the disruption of surface dust by motor vehicle activity. The wheels of the vehicles not only impart kinetic energy to particles on the road but also grind up the larger, nonsuspendible particles into smaller ones and break up the cohesive bonds of the dust. Such activity in an urban area occurs primarily on paved roads with additional local impacts expected due to dirt and gravel roads and parking lots. The amount of particulate reentrained by motor vehicles is directly related to the amount of dirt on the road, its suspendibility (sand versus dust), the speed of the vehicles, and the level of activity (often expressed as ADT - average daily traffic).

Vehicular activity on paved roads - The data gathered in the course of this study provided several opportunities for making estimates of the impact of vehicular-induced reentrainment by comparisons of comparable monitoring sites. The best data were the result of special studies that had been or were being conducted by the local agencies to determine for themselves the impact of traffic on the measured TSP levels. Generally, this was done by monitoring in one location but at either different heights or distances from the road, or both. The analyses of these data for each city are given in the individual city reports and the cross-city analysis is provided in Appendix E.

The findings from these data indicated that there was a direct relationship between the daily TSP concentrations and average daily level of traffic (ADT) and an inverse relationship between TSP and the distance of the monitor from the traffic, measured by the slant distance $\left(\text{SD} = \sqrt{(\text{height})^2 + (\text{distance})^2} \right)$. A comparison of the ADT/SD to the TSP concentration implied that a linear relationship could be assumed to exist with good correlation.

As is discussed more extensively in Appendix E, this relationship between ADT and slant distance has a significant impact on the interpretation of TSP levels measured by a hi-vol anywhere near a street with significant traffic. The data assembled in this study were not quite adequate to support development of a quantitative relationship suitable for accurate calculations;

however, it is possible to provide rough estimates of the impact of vehicular traffic on nearby hi-vols. The data in Table 11 are meant to provide approximate values suitable for identifying sites with potential problems and roughly judging the magnitude of the problem.

Table 11. APPROXIMATE IMPACT (IN $\mu g/m^3$) OF VEHICULAR TRAFFIC ON NEARBY HI-VOL SITES

Traffic volume, (ADT)	Slant distance of hi-vol from street (feet)			
	20	50	100	150
1,000	5	2	—	—
5,000	25	10	5	3
10,000	50	20	10	7
30,000	100	50	25	15

Vehicular activity on unpaved areas - In many urban areas dirt or gravel roads and parking lots are used by individual establishments or in industrial areas because of the expense of adequate paving. These areas can be sources of dirt for carryout to paved areas and may also serve as areas for naturally reentrained dust. In addition, vehicular activity on these areas can bring about man-induced reentrainment.

A comparison of the published emissions from unpaved roads with those of traditional emissions is given in Appendix E for those central counties analyzed in the course of this study. That analysis implies that the unpaved road emissions in counties which are not totally urbanized can be 10 to over 30 times the emissions from traditional sources. Even in urbanized areas, where unpaved roads are not common, the fugitive dust from unpaved roads may be over 10 percent of the traditional emissions in the county.

Based on the discussion on reentrainment from paved roads, which indicates that the impact of fugitive dust from vehicular activity decreases quickly with distance, it is felt that these numbers are inappropriate for direct use in air quality planning. If these fugitive dust emissions are treated the same as traditional emissions and used in rollback or dispersion modeling calculations, there would be excessive, undeserved emphasis placed on these sources and a potential deemphasis of the control of traditional sources. While these amounts of particulate may be temporarily reentrained due to vehicular activity, they are not suspended for any length of time. If they were, the rural areas of counties would be expected to have TSP levels as high as those found in the cities; such is obviously not the case. Therefore, the use, if any, of these numbers would have to be limited to inputs to models which adequately reflect the deposition and other removal of the particulates.

Specific Urban Sources

Certain activities in urban areas have not been considered major contributors to the TSP levels and therefore have received little attention in the formulation of control strategies for particulates. Yet these sources may be considered true emission sources because the particulates arise directly as a result of the individual activity rather than as a by-product, and several recent studies have suggested that these sources may be having more of an impact than previously thought. Of particular interest in a crowded urban area are transportation sources - the tailpipe emissions from automobiles and the emission of rubber due to tire wear. In addition, construction/demolition activities that are constantly occurring in cities add to the total TSP levels measured. Each of these sources is discussed below.

Transportation Sources - Although particulates from the transportation sector have been inventoried, they have seldom been regulated except through ordinances prohibiting smoking vehicles and Federal restrictions on aircraft. Controls on motor vehicles have centered around emissions of carbon monoxide, nitrogen oxides, and hydrocarbons, which are one to two orders of magnitude greater than emissions of particulates. In addition, particulates from the transportation sector have generally been assumed to be insignificant when compared with emissions from traditional sources. However, as emissions from traditional sources have been reduced under implementation planning, their proportionate contribution to the TSP problem has been reduced so that particulates from the transportation sector have become increasingly more important.

Tailpipe emissions — Attempts to separate out the contribution of motor vehicles to the total TSP measured have centered around the use of lead as a tracer element. In most urban environments where lead, copper, and zinc smelters, grey iron foundries, or other major point sources of lead are not prevalent, ambient lead levels are assumed to be due almost entirely to vehicular activity. Therefore, if the ratio of TSP emissions from tailpipes to the suspended lead emissions is known, the ambient levels of lead can be multiplied by this ratio to provide the ambient TSP contribution due to total tailpipe emissions. Based on several studies reviewed in Appendix E, this ratio may be assumed to range from 3 to 5 depending upon the vehicle type and age mix.

Ambient lead levels are routinely measured in major cities through analysis of NASN filters, and many state and local agencies also perform their own studies for lead. (California has an air quality standard for lead of 1.50 $\mu g/m^3$ for a monthly average.) Ambient lead levels contained in the National Aerometric Data Bank (NADB) indicate average annual concentrations ranging from 0.5 to 2 $\mu g/m^3$ with a few cities measuring 3 to 4 $\mu g/m^3$. These lead data suggest that tailpipe emissions are contributing from 1 to 20 $\mu g/m^3$ to the total particulate levels measured. Data collected from the individual cities studied under this effort indicate lead values in the middle range of those reported above; i.e., around 1 $\mu g/m^3$. Therefore, it may be assumed that tailpipe emissions are generally contributing 3 to 5 $\mu g/m^3$ to the ambient levels.

Special sampling studies conducted by EPA in Miami and St. Louis as part of this study provided data on particle sizes by elemental composition. Results in both cities indicated that the lead particles being sampled are extremely small. Only a small percentage are greater than 4 μm in diameter, and the largest percentage was collected in the last impactor stage, implying the particles had an effective aerodynamic diameter of less than 0.25 μm. This small diameter means that the lead would be dispersed and transported much as a gas with very little fallout with distance. Therefore, it may be expected to be measured at rooftop levels or even in more remote areas.

As part of this special study conducted by EPA in Miami, 2-hour elemental concentrations were compared with the hourly traffic counts for 1 week. These data illustrated the expected relationship of increasing lead concentration (as high as 4.6 $\mu g/m^3$ for a 2-hour average) with increasing traffic, especially in the early morning when rush-hour traffic started and before mixing height and wind speed increases caused a drop in lead concentration.

A compilation of all the sites for which some lead data were available provided 49 monitors from six cities (Baltimore, Miami, Oklahoma City, Philadelphia, San Francisco, Washington) with annual average lead concentrations as well as individual filter analyses from several sites in the other cities discussed above. Those monitors with annual data were grouped according to their site classifications and then averaged to provide a mean concentration. Because the monitoring sites had a wide range of local influences affecting the measured lead levels, Figure 10 presents not only the mean values for each of the site classifications but also the range of values found. Since there were only four monitoring sites each for the classification of rural and industrial, these averages and ranges may not be representative of situations found in other cities.

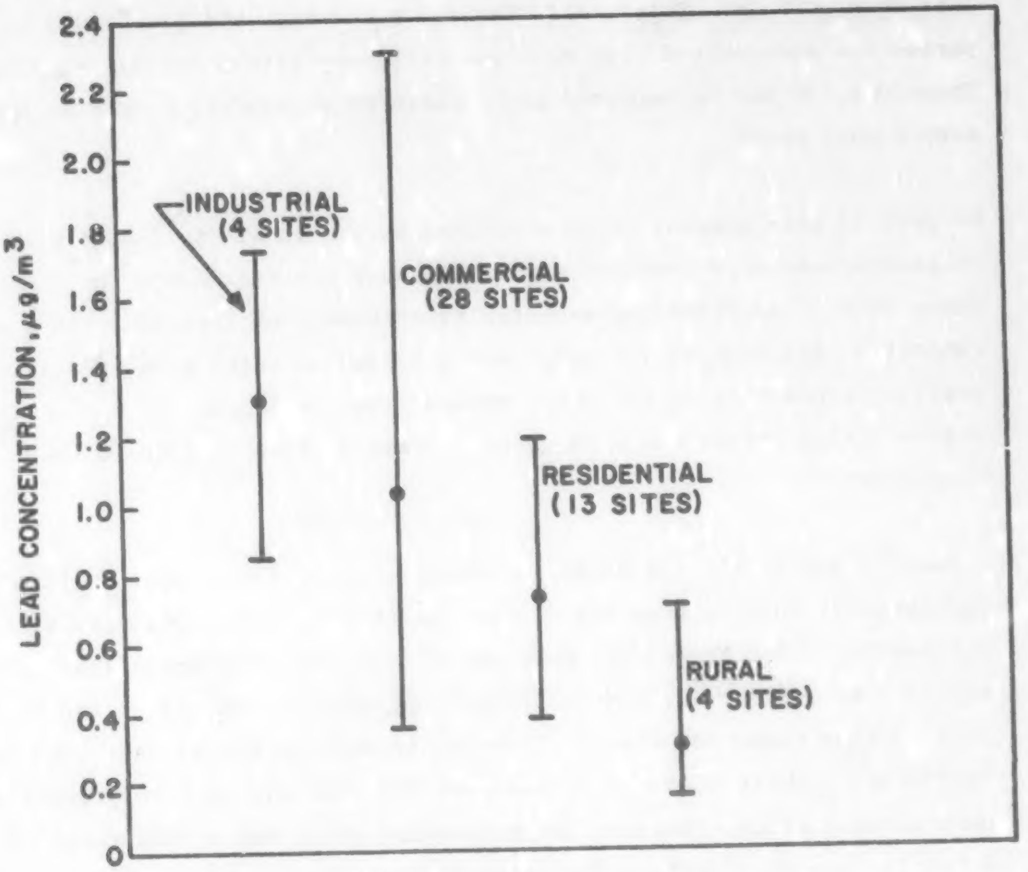


Figure 10. The range and average lead concentrations found at monitoring sites

Tire wear - Aside from direct tailpipe emissions and reentrainment dust, automobiles are known to generate particulates simply from the deterioration of the body and parts. Rust, corrosion, and friction of one part on another are all known sources. However, their magnitude is small compared with the wear that is seen on tires. In the U.S., an estimated 660,000 tons of tire-tread are worn away each year. Since over half of all vehicle-miles traveled (VMT) is in urban areas, approximately 350,000 tons of rubber are added to the urban environment every year. Considering the size and widespread nature of this source, its impact on air quality warrants study.

Although filters were selected from each city for microscopic analysis, neither the selection of a few filters nor the accuracy of the microscopy were believed to be sufficient to characterize the cities. However, the numerous filters from among the cities were considered to be adequate for averaging contributions according to the various classifications for the monitoring sites.

By using the percentage contribution of rubber tire fragments to the total visible loading on the hi-vol filter (diameter > 1 μm) and the assumption presented in Section II that approximately 85 percent of the loading was visible, average rubber loadings can be calculated for each site type. These average values, along with the range of values observed, are plotted in Figure 11. This figure shows that commercial sites, generally most exposed to traffic, have the highest contribution of rubber while undeveloped or rural sites barely measure any rubber. (Note cautions in derivation given in Appendix E.)

In the course of the careful evaluation of the monitoring network in each city, monitoring sites were also rated on the basis of local influences, including paved roads. Sites with an expected paved road influence (10 in all) had rubber concentrations twice as high as sites for which no such influence had been noted - 9.9 and 4.9 $\mu g/m^3$ respectively.

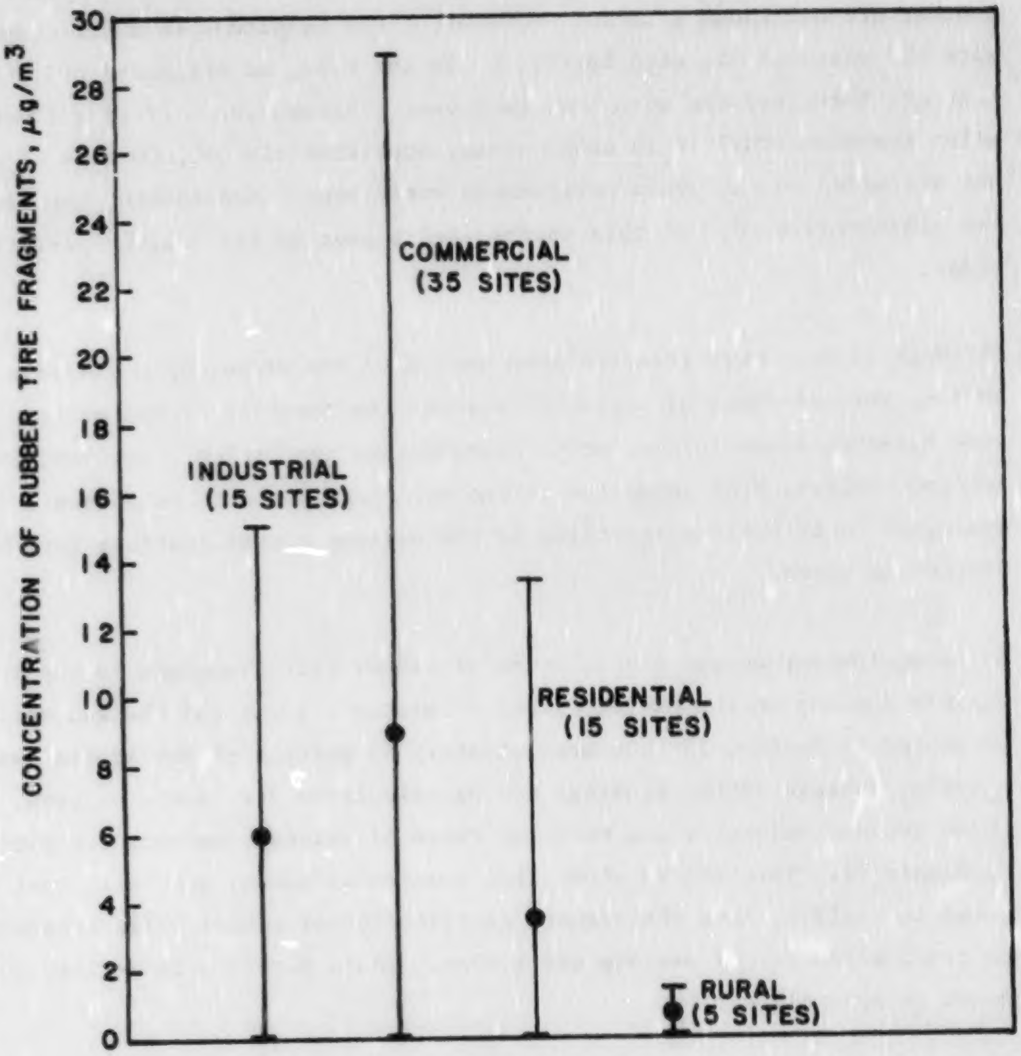


Figure 11. Average and range of TSP loadings due to tire wear at different monitoring site classifications

The values found for rubber in the course of this study are several times what were expected based on the literature reviewed. The reason for this discrepancy is not apparent. This experiment may have been better formulated than previous ones to give a good cross-section of values, or the high levels may be an artifact of the monitoring site and filter selection. Currently, however, there is no reason to doubt the validity of these data.

Of some interest in planning for control is the particle size distribution of the rubber. As shown in Table 7, the average size range of the rubber tire fragments (13 to 135 μm) is much larger than that of any other particulate identified. Some particles were found to be 200 μm in length. Normally, such large particles are not considered suspendible for any length of time and are too large to be of concern for respiratory effects. Despite their size, however, no difference was discernible in average concentrations of rubber by monitor height. Several monitors 50 to 100 feet above ground level measured levels of rubber in the 5 to 15 $\mu g/m^3$ range while other, lower monitors recorded no rubber.

Construction/Demolition - The movement of materials associated with construction and demolition activities usually results in the emission of particulates into the ambient air. Major demolition programs, whether using a ball and crane or blasting (low-yield), will emit particulates up to a height equal to that of the building being removed. Construction involves much more movement of materials continuously for periods of several months to over a year. Emissions are generated by a wide variety of operations over the duration of the construction, including land clearing, blasting, ground excavation, and on-site traffice, as well as the construction of the facility itself.

The study findings in Appendix E illustrate that construction activity does have an impact on very local TSP levels but that the effect is not readily predictable. Construction will generally elevate concentrations downwind from the site for distances up to a mile; the amount of increase is related to the level of activity, type of activity, distance from the activity, and control measures employed. Monitors within half a mile of construction may have annual geometric means 10 to 15 $\mu g/m^3$ higher than normal. Therefore, if 10 percent of the monitors in an urban area are near construction activity, the calculated citywide average TSP level would be 1 to 2 $\mu g/m^3$ higher than otherwise expected.

These measured impacts are much less than would be expected based on a simple interpretation of the emission levels developed for each county (see Appendix E). Obviously, the use of those emission levels must be restricted to input into modeling programs which adequately account for the fallout and deposition of particles. Development of new emission factors to reflect the type and degree of activity and any control measures would be more appropriate than the use of the existing factors.

National Assessment

While the above discussions have not covered all topics possible under the heading of nontraditional sources, they did center on those sources that have been identified as probable major influences. From these sources alone it is evident that there are contributions to the total TSP levels simply from man's activity and that the contributions are the highest in an urban area where man's activity is greatest. Similarly, the closer to the activity, the larger the impact. These variations have been addressed above for each of the sources, but an overall combined assessment is needed to indicate the extent of the total impact of nontraditional sources on TSP levels, and thereby on the problem of attaining standards.

Because of the range of TSP levels that may be contributed by the various nontraditional sources, it is not possible to identify at this stage either the exact impact at any monitoring site or even the average impact in any one city. Such a determination would require extensive data and modeling, most of which are not available. Rather, the intent is to provide a measure of the range of impacts that may reasonably be expected in most situations and an understanding of the relative importance of nontraditional sources for standards attainment on a national basis. Therefore, this conclusion should not be taken as sufficient to preclude detailed analysis in each city but as guidance to the development of national priorities for further planning measures.

The average and range of TSP levels attributed to tailpipe emissions and tire wear were given in the above analyses by site type. Recognizing that ranges of values varied in different cities, average contributions can still be calculated. Tailpipe emissions provided an average level of TSP in industrial and commercial areas of 4 to 5 $\mu g/m^3$ and approximately 3 $\mu g/m^3$ in residential areas. Tire wear added rubber concentrations of 6 $\mu g/m^3$ at industrial sites, 9 $\mu g/m^3$ at commercial sites, and 3 $\mu g/m^3$ at residential sites.

Construction activity is more difficult to present on an average basis because of the wide range of possibilities that may occur. Some cities have construction underway at individual, widely dispersed locations which are not close to monitoring sites, while others may have similar activity but close to one or more monitoring sites. Levels of TSP due to construction are expected to range between 0 and 15 $\mu g/m^3$; the closer the monitor, the greater the impact. If only one or two monitors out of a network of 20 are near construction activity, a citywide average will only be affected by 1 to 2 $\mu g/m^3$ annual geometric mean. However, in some cities major construction programs such as urban renewal and subways are going on in concentrated areas of the city. These activities are apparently causing higher-than-normal values at a large number of nearby monitors and will provide elevated average values in the commercial section of the city.

While construction is obviously a localized source, the reentrainment problem exists wherever there are roads and traffic. Since the level of reentrained matter could not be exactly determined through microscopy or elemental analyses, as with rubber and tailpipe emissions respectively, other measures were necessary. By calculating the excess levels at residential, commercial, and industrial sites that could not be explained after accounting for nonurban levels and traditional sources, the total nontraditional impact on the annual geometric mean TSP levels averaged around 20 to 25 $\mu g/m^3$ at residential sites and 30 to 35 $\mu g/m^3$ at commercial and industrial sites. By subtracting the above levels estimated to be due to tirewear, tailpipe emissions, and construction, the average contribution due to reentrainment and any other nontraditional sources would be approximately 20 $\mu g/m^3$ at industrial monitors, 18 $\mu g/m^3$ at commercial monitors, and 14 $\mu g/m^3$ at residential monitors. (The higher levels at industrial monitors are likely the result of dirtier roads in the area.) These levels of TSP were compared with those calculated in specific studies in Miami and Providence, by using the distribution of monitor siting situations and the expected impact of reentrainment at each site, and also with projected reentrainment levels based on published reports of the ratio of tailpipe TSP to reentrainment TSP. The same order of magnitude was found in all cases.

Figure 12 indicates the quantitative impacts on TSP levels of each of the nontraditional sources considered above in various types of neighborhoods. As has been stressed throughout this discussion, these are only average values and a wide range of values can be expected when comparing particular situations.

MONITORING CONSIDERATIONS

The monitoring of ambient TSP levels is not a causative factor in the attainment of standards in the same sense as high nonurban levels or emissions from either traditional or nontraditional sources. However, network configuration and station siting do affect the extent to which measured levels are representative. These factors also affect the overall quality and usefulness of the data base needed for both air quality planning and verifying attainment.

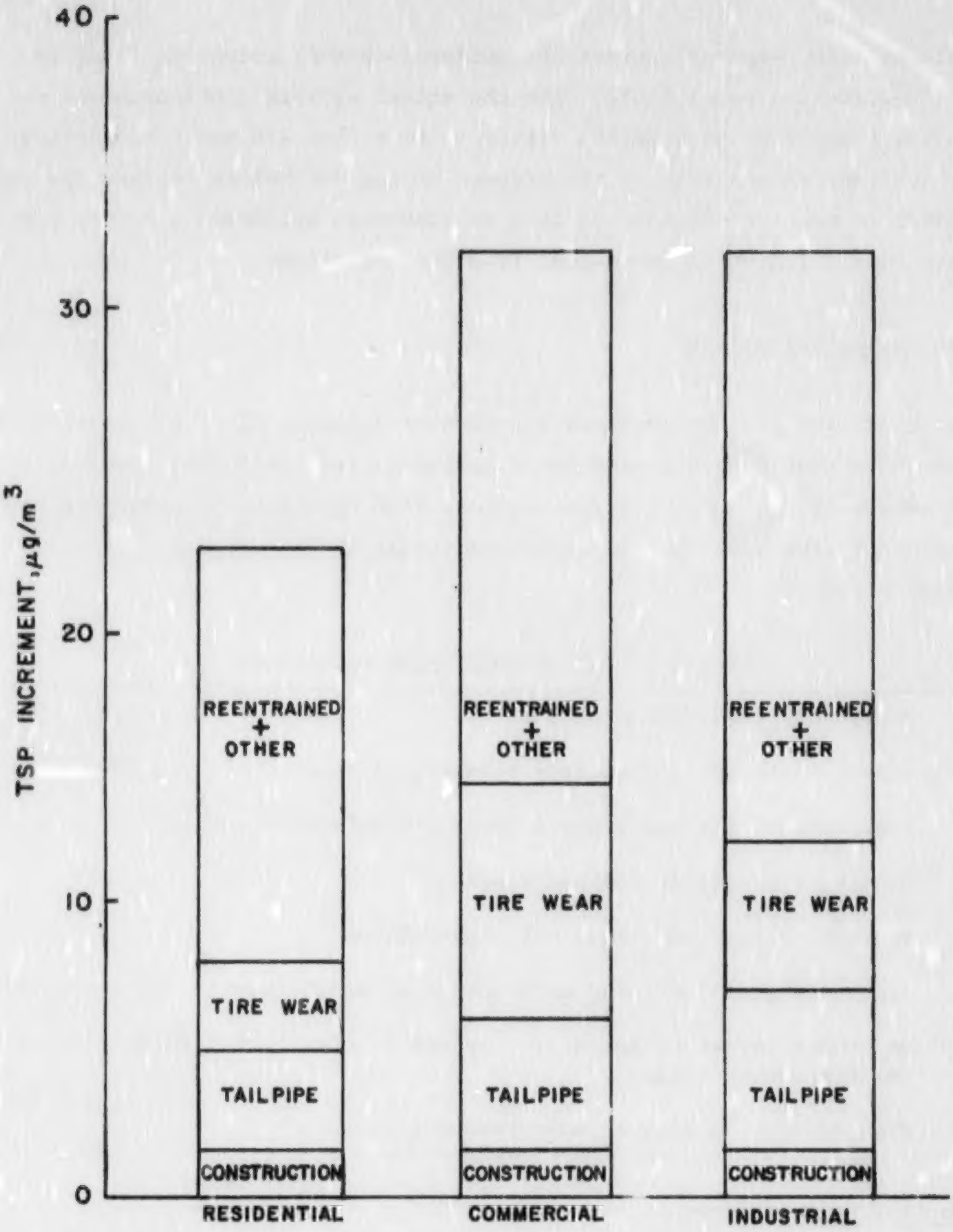


Figure 12. Nontraditional source increments at different site types

This section compares current EPA guidance on monitoring, as found in OAQPS Guideline No. 1.2-012, with the actual network configurations and siting practices found during visits to more than 150 monitoring sites. It contains an analysis of the effects of the variations in networks and siting on measured levels and thus on standards attainment, and an analysis of the impact of deviations from EPA guidelines.

Monitoring Objectives

Table 12 from the EPA monitoring guideline document lists the objectives that have been commonly used in designing current networks. Basically these are the outgrowth of the original NASN objective of surveying typical pollutant levels, with some recent additions in the areas of planning and enforcement.

Table 12. GENERAL MONITORING OBJECTIVES

- Provide data for research
- Provide data for air quality planning efforts
- Provide data for emergency episode prevention
- Monitor time trends and patterns
- Monitor source compliance with regulations
- Ascertain attainment and maintenance of NAAQS (population exposure)
- Determine impact of specific proposed or constructed facilities on ambient concentration
- Provide data to support enforcement actions

Monitoring Guidelines

The current EPA monitoring guidelines define a general structure for discussion and planning network monitoring objectives, emphasizing the need to design the network to meet well-defined objectives and data needs. They prescribe the general size of monitoring effort required, emphasizing that this must be adjusted to suit local conditions. More specifically concerning hi-vol placement, the guidelines recommend a horizontal clearance of at least 2 meters and a height range of 2 to 15 meters; this latter permits placement at any height from essentially ground level to about 50 feet.

Network Configuration

The concept of network configuration involves the number of monitoring sites and their geographic distribution over the area of concern. It includes both the concept of selecting patterns of sites and areas of cities over distances of several miles and the concept of selecting neighborhoods over distances of a few city blocks.

Configuration Problems - In general, the monitoring networks studied in the 14 cities did not have major problems with overall configuration. However, two problems of some concern in several of the cities do warrant further discussion. These problems were the general lack of stations to measure incoming air mass concentrations and the lack of clearly defined industrial area monitors in several cities.

The widespread lack of relatively remote stations is to some extent a matter of policy and agency jursidiction as well as a matter of network design. For only a very few of the urban areas studied was there an appropriate station to measure the TSP loadings of incoming air masses. Previously operated nonurban sites have been abandoned in two areas, while in many they never existed. When necessary for air quality planning, a TSP concentration in incoming air is typically just assumed, usually based on the NASN nonurban sites, which are frequently not appropriately near.

This lack of adequate nonurban data is not yet a serious problem in major industrialized urban areas, where ambient levels typically exceed the standards substantially, so that precise knowledge of incoming levels is not yet necessary. However, it will no doubt become increasingly problematic as ambient levels approach the standards, and as improvements in air quality require increasingly precise planning. In those study areas where levels are nearer the standards, particularly those areas where traditional sources are not dominant, there is already a planning problem resulting from the lack of precise knowledge of the transition in levels from remote through suburban into urban areas. This problem is of additional concern in regions of the country where we find significant levels of secondary pollutants of generally unknown origin.

The second area in which there were some problems with network configuration is the matter of sites in industrial areas. In some of the heavily industrialized urban areas studied, there were clearly defined industrial sites, located either within the industrial area or along the margins between industrial and residential areas. At these sites, there was no real question about the air quality influence of the industrial areas and operations, and the trend or lack of trend in industrial emissions was clear. In other areas, however, the sites best described as industrial were not in fact located in or representative of the most uniformly dense industrial areas, but rather were often influenced primarily by one nearby industrial source. Consequently, the air quality impact of the city's industrial areas is not clearly monitored, and the effects of control efforts are not readily seen. The reason for these problems is primarily the nature of the industrial areas themselves. In the areas that are well monitored, the industrial activities are typically iron and steel mills and associated metallurgical operations, usually located in large, contiguous, readily identifiable areas. In contrast, the poorly monitored areas are in long, narrow riverside flood plains and contain much more heterogeneous industrial activity, with extensive warehousing, truck and rail terminals mixed in. Another somewhat similar problem is the matter of agency jurisdiction. Not accidentally, major industries are frequently located just beyond city boundaries, either in smaller satellite municipalities or in unincorporated areas, and hence tend to escape thorough coverage in a network focused upon the responsibilities of a city agency.

This is clearly a difficulty occurring in Philadelphia, where a major heavy industrial area extends from the edge of the city along the riverfront in adjacent counties and into adjacent states.

Air Quality Patterns - Based on site visits, over 150 hi-vol sites were classified as nonurban, residential, commercial, or industrial on the basis of the principal impact on air quality, rather than strictly on location; that is, a site in a residential neighborhood that received a major impact from an adjoining industrial area was categorized as industrial rather than residential. A consistent pattern appeared when the sites were grouped by the four neighborhood types. In each urban area, the average air quality levels were lowest in the residential neighborhoods and highest at the industrial sites. Table 13 compares average concentrations by site type after those sites that are unduly affected by nearby sources (in addition to an areawide influence) were removed from the data base. Not surprisingly, industrial sites were systematically higher; traditional sources have long been recognized as a major source of air pollution. However, it is also important to note that commercial sites were similarly higher. This is because the potential for automotive-related pollutants (such as exhaust particles, rubber tire particles, and other types of reentrained street dust) is greater in commercial areas than in residential areas due to increased vehicle miles traveled (VMT).

Because ambient air quality levels in different types of neighborhoods show such distinct differences, it is important to consider network configuration, especially the representation of industrial neighborhoods, in any comparison of air quality between cities. Failure to do so might very well result in faulty conclusions about the effectiveness of regulations, the relative contributions of source categories, or any other objective of the comparison.

Table 13. AVERAGE ANNUAL TSP CONCENTRATIONS BY NEIGHBORHOOD TYPE

Cities	No. of sites studied	Geometric mean TSP concentration above nonurban levels, µg/m³		
		Residential	Commercial	Industrial
Category I				
Cleveland	11	45	86	113
Birmingham	13	35	56	88
St. Louis	22	29	41	74
Average		36	61	92
Category II				
Philadelphia	10	26	48	58
Baltimore	9	30	40	71
Cincinnati	12	24	36	66
Average		27	41	65
Category III				
Chattanooga	8	20	42	54
Denver	6	48	81	96
Seattle	7	21	33	62
Providence	8	18	29	None
Average		27	46	71
w/o Denver		20	35	58
Category IV				
Washington, D.C.	9	17	30	None
Oklahoma City	14	26	49	None
Miami	13	24	36	None
San Francisco	11	24	31	None
Average		23	37	None

Station Siting

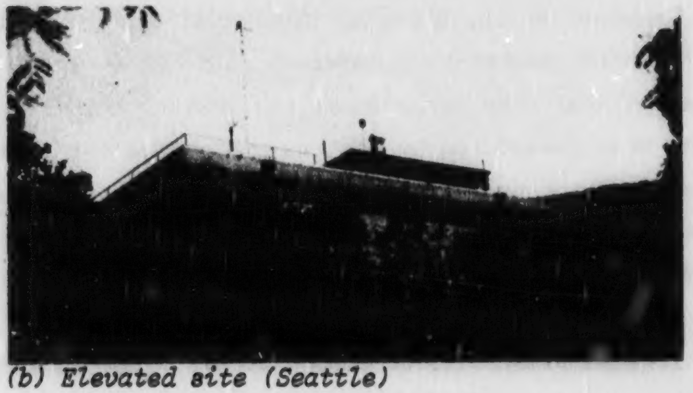
The selection of the actual site for placement of the hi-vol is a major consideration. As a matter of historical practice, siting decisions have usually been made on the basis of more practical matters, such as building access, security, power availability, and so on. However, the principal factors to consider on a technical basis are the effects of height and distance from the street, and any nearby sources of particulates.

Height Effects - The primary problem with siting is the height of the hi-vol above the ground or street level. The height issue is difficult because the traditional practice is to put hi-vols on rooftops, while the more recent view of some is that the health-oriented spirit of the Clean Air Act should mandate placement near the breathing zone.

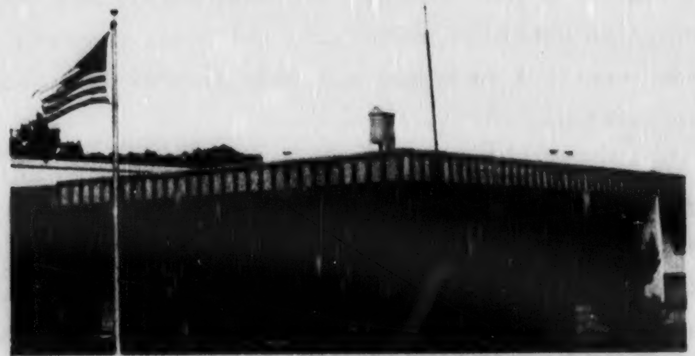
The original decision in favor of placing hi-vols on rooftops rather than at street level, first made in establishing the NASN in the early 1950s, considered the fact that such siting would minimize the measurement of particulate matter reentrained from the ground. (The other significant reasons were concern over vandalism and the fact that ground-level sites are hard to find in the CBD.) The fact that these original monitors were deliberately placed where measurement of reentrained particles would be minimized emphasizes the changing concept of the TSP problem. Today low-level, reentrainment-type emission sources are seen by many cities as the reason that they cannot meet the ambient standards, but in the 1950s they were considered by most as extraneous interferences, not pollution sources; the pollution sources were the heavy industries and the large fuel combustion operations. The EPA monitoring site guidelines (OAQPS No. 1.2-012) state that the priority area for sampler location is the zone of highest pollutant concentration, yet it also states that "only rooftop sampling is recommended to avoid the influence of possible reentrainment of particulates close to the ground." Consequently, appropriate siting of hi-vols is still an issue today, and the inconsistencies, both among sites within an urban area and among networks in different urban areas, continue to hamper not only careful data analysis but also problem definition.

Typically, hi-vol heights range from ground level to the top of many-story buildings; Figure 13 illustrates three points on this range: a low-level (6 foot) site type routinely used in Birmingham; an unusually high site — the "Food Circus" building in Seattle at 70 feet; and a more typical site — a one-story fire station in Oklahoma City. In general, sites of all these varieties are present in each network, but on an overall basis there is a significant difference among cities in the average height of the hi-vols. Table 14 shows the variations in monitor height among the 14 cities. Clearly, variation is significant.

(a) Low-level site (Birmingham)



(b) Elevated site (Seattle)



(c) Sites of typical height (Oklahoma City)

Figure 13. Range of heights in typical hi-vol installations

The distance of the hi-vol back from the nearest street is often related to the vertical height because of the relationship of general building size and neighborhood type. The typical central business district (CBD) site on a tall building will be both vertically higher and horizontally nearer to the street than a residential site, which may well be on a one-story building but is more likely to be set back from the street a significant distance. Distance back from the street is clearly a somewhat more flexible parameter than height, as the hi-vols can usually be moved about on a rooftop. The analyses of dust reentrainment from streets in Appendix E found that there was some evidence that TSP levels were more affected by variations in height than by distance back from the street.

Table 14. VARIATION IN MONITOR HEIGHT AMONG THE 14 CITIES

Cities	Height of monitors, feet	
	Mean	Median
Heavily industrialized		
Cleveland	37	25
Birmingham	10	6
Philadelphia	14	13
Baltimore	31	30
St. Louis	38	19
Moderately industrialized		
Cincinnati	29	25
Chattanooga	21	19
Denver	30	23
Seattle	34	20
Providence	56	49
Lightly industrialized		
Washington, D.C.	33	28
Oklahoma City	17	15
Miami	20	18
San Francisco	30	18

Impact of Nearby Sources — The exact placement of a hi-vol with respect to other types of sources can also have a significant impact on the levels measured. This is particularly true at sites that are at all proximate to low-level dust entrainment sources, such as unpaved parking lots or roads, construction activity, sources of fugitive emissions, and industrial sources with much settleable particulate or low-level emission points. The sites visited in the study were classified as to whether any nearby source had an undue influence on the measured levels; Table 15 summarizes the number and type of sites with nearby sources. It is apparent from the table that a significant fraction of the hi-vols in most of the cities are influenced by nearby sources, and significant changes in concentrations at these sites are dependent on controlling the nearby source. In many cases, the source is nontraditional or is related to fugitive dust.

Only three residential sites had special local impacts, but in the commercial and industrial categories such influences were common. Ten of the 60 commercial sites had local impacts, even when a fairly stringent definition of undue influence was used. For example, since so many commercial sites had an obvious impact from traffic, such an influence was labeled an undue effect only if the monitor was either unusually low and close to the street (less than about 15 feet off the ground or 25 feet from the road as in Figure 13(a)) or affected by a major street, as in the case of samplers adjacent to expressways. Construction, a cause of special local impacts at three sites in 1974, was identified only if it was immediately adjacent to the site (within one or two blocks) and if the impact on air quality levels was apparent.

The 41 industrial sites presented a different situation. As initially classified, essentially all the industrial sites had impacts from nearby unpaved roadways, parking areas, trucking terminals, and other fugitive dust sources. Consequently, it was deemed appropriate to include these impacts in the basic concept of an industrial neighborhood, and no industrial sites were classified as having undue impacts. Some sites in

Table 15. NUMBER OF SITES WITH AN ESTIMATED IMPACT OF LOCAL INFLUENCES, BY NEIGHBORHOOD CLASSIFICATION

	Residential	Commercial	Industrial	Undeveloped	Total
Total number of sites visited	39	60	41	14	154
Number with some apparent degree of local impact	10	36	24	0	70
Number with degree of impact judged major	3	10	21	0	34
Number with "undue" impact in context of neighborhood definition	3	10	0	0	13
Average TSP levels at sites without "undue" impact	60 $\mu g/m^3$	78 $\mu g/m^3$	110 $\mu g/m^3$	-	-
Typical increment at sites with "undue" impact	15 $\mu g/m^3$	25 $\mu g/m^3$	-	-	-

commercial neighborhoods, however, were so classified on the basis of undue impacts from isolated industrial sources.

Air Quality Patterns — Approximate impacts of nearby sources of various types were estimated and are summarized in Appendix G. Also determined were the impacts of sources of fugitive emissions, generally identified as being in the immediate vicinity of the monitor; these impacts were discussed in the section on traditional sources.

The typical effect on air quality levels at sites with significant impact from nearby sources can easily be 20 to 25 $\mu g/m^3$. This represents an increase of at least 30 percent over the typical levels recorded at commercial neighborhood sites in the 14 study cities. Data at specific sites can vary substantially from these average values, depending on the proximity of the source to the site.

Comparison of Actual Siting to Guidelines - The general conclusion regarding siting of the monitors visited is that they are altogether too loosely placed with respect to both height and horizontal placement. However, they are generally within the height range specified in the EPA guidance material, which recommends sites less than 50 feet high, and provides only qualitative cautions concerning horizontal placement. Thus, it is concluded that more definitive guidance is needed, particularly on height and proximity to nearby sources, such as paved roads.

Operating Frequency and Schedule

Designing the frequency and scheduling aspects of TSP network operations is generally a matter of balancing the precision desired or required in the resultant annual mean with any necessary resource restraints. These decisions are not generally a major problem in designing a network and the matter of operating schedules was not found to be, in and of itself, a significant factor relative to standards attainment. Common practice in the networks studied was to sample on a systematic schedule every 6th day, following recommended EPA guidance; this is generally adequate to produce acceptable estimates of the annual mean and the frequency of violations of the 24-hour standard.

The only significant interaction between hi-vol operating frequency and the problems of standards attainment is a matter of having enough data to provide adequate knowledge of the air pollution problem to be dealt with. As an example, the analyses of meteorological parameters and TSP levels in Section III and Appendix F, conducted to investigate the impact of urban fugitive dust influences, were dependent on having essentially daily hi-vol data available; in other urban areas where similar detailed analyses would have been important for judging the cause of the TSP problem, data gathered on the standard every-6-days schedule proved to be completely inadequate for a proper analysis. This is believed to be a fairly common failing because the very nature of particulates from urban activity makes the problem closely interrelated with meteorology. Since the problems of fugitive dust emissions, resuspension of material from the roadway, etc., are increasingly being blamed for failure to attain the standards, increased sampling frequency should appropriately be a part of agencies' attempts to define this problem adequately for planning purposes.

Summary

The degree to which monitoring considerations influence the attainment of standards is philosophically difficult to assess. The matter of network configuration, or neighborhood selection, is difficult because there are no clear criteria for defining proper configuration; it would necessarily be a function of the purpose of the monitoring. The matter of individual site placement is philosophically difficult because it gets into the vague area of defining the dividing point between "ambient" air, where the standards should be met, and source-oriented monitoring sites.

Network Configuration — The selection of neighborhoods for monitoring reflects a difficult tradeoff between the various monitoring objectives. Selecting residential neighborhoods will provide better population-exposure coverage but will likely result in lower values than selecting commercial neighborhoods. Industrial sites, in turn, will have higher values than commercial sites, but will provide necessary information on the progress of traditional source control. One obvious conclusion relating to network configuration is that the latitude air pollution control agencies necessarily have in the design of their networks can easily affect the number of sites in the jurisdiction that attain the standards. However, this is a concern over the relative balance between residential, commercial and industrial sites in the network, which doesn't necessarily relate to the overall effect of the control program on the aggregate exposure of the population. One obvious approach to this, which is simple at least in theory, is to designate smaller subnetworks for various purposes, each of which might have a different balance of sites.

Hi-vol Siting - For certain specific sites, the difference between attaining and exceeding the standard is very clearly attributable to the special influence of some nearby source. Philosophically, this situation could be viewed either of two ways. It could be called a sampler siting anomaly, which should be resolved by moving the hi-vol or redesignating it a source-oriented research station. Alternatively, it could be viewed as a site receiving an impact from a pollution source which, though possibly temporary or of a fugitive dust nature, is still something that should be controlled. Which of these two interpretations is appropriate depends on the precise nature of the site in question. Since public access has been presumed by EPA to be the criterion for defining ambient air, the key parameter is the extent to which the public has access to the site in question. The interpretation of public access may prove difficult, however. For instance, the Dyer Street site in Providence, which exceeds the standard because of the impact of an expressway, is located on a parcel of right-of-way land immediately adjacent to the expressway. While the public technically and legally has access to the parcel, as a practical matter the general public has no reason to go there, and in fact there appears to be no significant pedestrian volume.

In assessing the overall impact of undue influences from local sources, the important factor is the proportion of sites falling in each of these two categories. Based on the site visits and the above philosophy on interpretation of public access, the significant majority of cases appear to be situations where the source should be controlled, and the instances of true monitoring anomalies which should be corrected are a small minority.

In a position somewhat between these latter two situations is the group of sites that have significant but temporary local influences, usually construction. These are to a certain degree clearly controllable fugitive dust problems; because of their transitory nature, however, some portion of the impact must be written off as an anomaly.

Another obvious conclusion is that, because nearby sources do affect measured air quality considerably, the siting practices of the agency can significantly affect the number of sites indicating violations. Consideration of the siting practices of the agency is thus a necessary prerequisite to comparing air quality values between cities.

METEOROLOGY AND CLIMATOLOGY

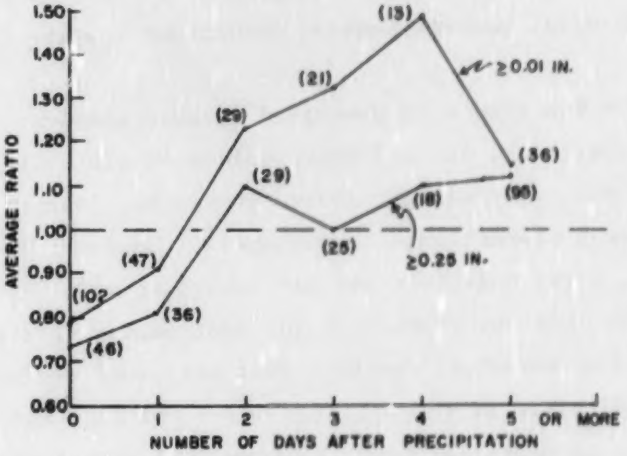
General Considerations

In determining which AQCRs have met or are likely to meet the national particulate standards and which, if any, are not, it is important to keep in perspective the role of meteorology and climatology. As part of this goal, the following discussion summarizes the impact of certain meteorological variables and meteorological conditions on TSP levels in as quantitative a fashion as appears reasonable at the present time.

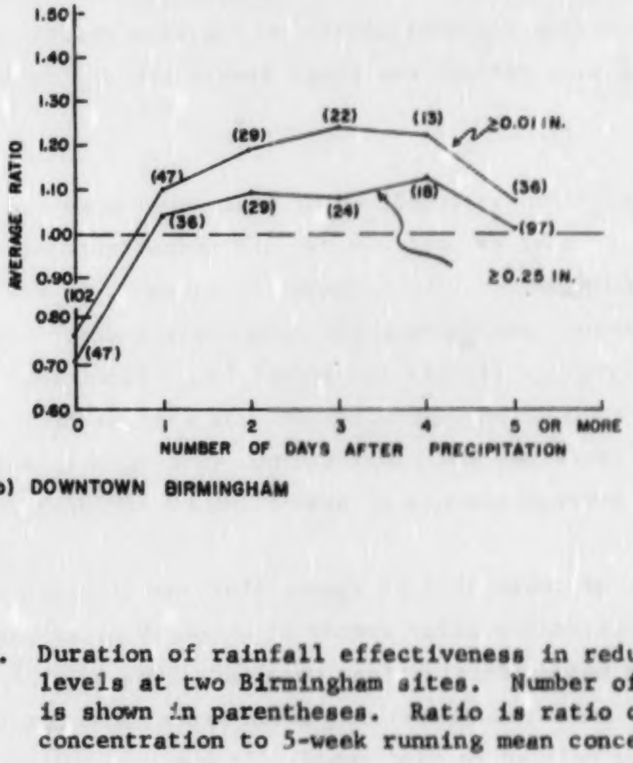
The principal effects to be considered are discussed at length in Appendix F where the range of conditions experienced by the 14 study cities is analyzed. A brief discussion of these findings follows.

Precipitation - The effect of precipitation is twofold: (1) it cleanses the atmosphere by capturing particles within the cloud (rainout) and by the washout of particles below the clouds; and (2) it suppresses fugitive dust. Precipitation is very effective in reducing TSP levels in areas with high concentrations which have resulted from either industrial or fugitive dust sources, and average concentrations decrease steadily with increasing 48-hour precipitation amounts in these areas. The effect of precipitation is greatest on the day it occurs and lasts an average of about 2 days. In the city case studies of high-concentration areas, concentrations measured during the last half of a 48-hour period with precipitation $\geq$ 0.25 inch averaged approximately half of concentrations measured during 48-hour periods with negligible precipitation. Concentrations at typical urban sites (excluding clean residential areas) on days with measurable precipitation were about 75 to 85 percent of average values for the site and time of year. In arriving at these estimates, no attempt was made to distinguish between the effects of precipitation itself on TSP levels and the effects of associated changes in other meteorological conditions.

Figure 14 presents a graphical summary of the findings at two sites in one of the study cities when different levels of 24-hour precipitation are used to classify a day as one with precipitation. Under one analysis, any day with measurable precipitation (0.01 inch) was considered to have had precipitation; in a second analysis, only days with at least 0.25 inch of precipitation were considered as days with precipitation. Figure 14 shows that, on the average, TSP levels remain depressed the day after rain at North Birmingham; at Downtown Birmingham the levels return to near normal more quickly. The effect of rainfall of different intensities is shown by



a) NORTH BIRMINGHAM



b) DOWNTOWN BIRMINGHAM

Figure 14. Duration of rainfall effectiveness in reducing TSP levels at two Birmingham sites. Number of observations is shown in parentheses. Ratio is ratio of 24-hour concentration to 5-week running mean concentration

the difference between the two curves for each site. The occurrence of the peak average ratio at 4 days after precipitation at North Birmingham reflects a few very high ratios apparently associated with periods of dry, light-wind, poor-dispersion conditions lasting for several days.

Windspeed — The effect of windspeed is also complex. As the speed of the wind increases, the effective volume of air available for dilution increases and, for constant source strengths, downwind concentrations are inversely proportional to windspeed. However, in the case of particulates, total emissions are not invariant with windspeed since the wind is the agent by which soil and dust particles are naturally entrained. The amount of fugitive dust entrained depends on the moisture content and nature of the soil (or dust) and the wind speed. At speeds below 10 to 15 miles per hour, however, the amount is basically negligible even under dry conditions. At greater average speeds, and particularly under gusty conditions, fugitive contributions can be substantial. Wind speed also indirectly contributes to fugitive emissions by increasing the rate of evaporation, and hence speeds the drying of the soil and dust particles.

Specific analyses on the effect of wind speed were conducted in four of the study cities using 24-hour average TSP concentrations and daily average airport wind speeds. One of these (Birmingham) is heavily industrialized, two (Chattanooga and Denver) are moderately industrialized, and one (Oklahoma City) is lightly industrialized. Birmingham and Chattanooga have above-average precipitation and low average wind speeds, Denver has little precipitation and below-average wind speeds, and Oklahoma City has nearly average amounts of precipitation and high average wind speeds.

The results of these studies showed that the dilution effect of wind speed was noticeable below speeds of about 10 miles per hour in industrial areas where major contributions were made from point sources. At higher wind speeds and in nonindustrial urban areas, average TSP levels did not appear to be related to wind speed. It was not possible to discover to what extent this invariance with wind speed resulted from an interplay between dilution and wind-induced fugitive dust contributions. However, the findings in Birmingham apparently indicate some reentrainment of particulates at high wind speeds. As shown in Figure 15, the average concentration decreases with increasing wind speed for speeds up to about 8 knots and then remains essentially constant. Furthermore, the decrease of average concentration with wind speed, as shown by the dashed line, is approximately linear from 2 to 8 knots, as would be expected if dilution were the controlling influence. The change in slope shown at 2.5 knots can be attributed to stagnation conditions at very low wind speeds. While the curve for North Birmingham reflects the same relationship as that for Downtown Birmingham, the average concentration at Mountain Brook appears to be invariant with wind speed. This difference may be explained by the availability of particles for reentrainment being very low in the residential areas. The industrial site, being in a dirtier area, has a larger amount of particulate that can be reentrained.

Stability and Stagnation — The stability of the air, as measured by the change of temperature with height, controls the rate of vertical turbulent diffusion and the mixing depth. It therefore is a measure of the dilution power of the atmosphere in the vertical. The diurnal variation of wind speed caused by the vertical transfer of momentum is closely related to the diurnal variation in stability. Stagnating air masses permit the accumulation of pollutants and the development of stable transport patterns.

While no special attempt was made during this study to isolate the effects of stability or stagnation periods on TSP levels, several general statements can be made. First, the highest 24-hour concentrations are observed during stagnating conditions since by definition these are periods with very low wind speeds and inversion conditions over at least a 24-hour period. Under these conditions, concentrations are typically about two or two and a half times the average values for the site and time of year, and the 24-hour standards are most likely to be exceeded. In the more polluted areas, levels may be increased 100 $\mu g/m^3$ or more. For that

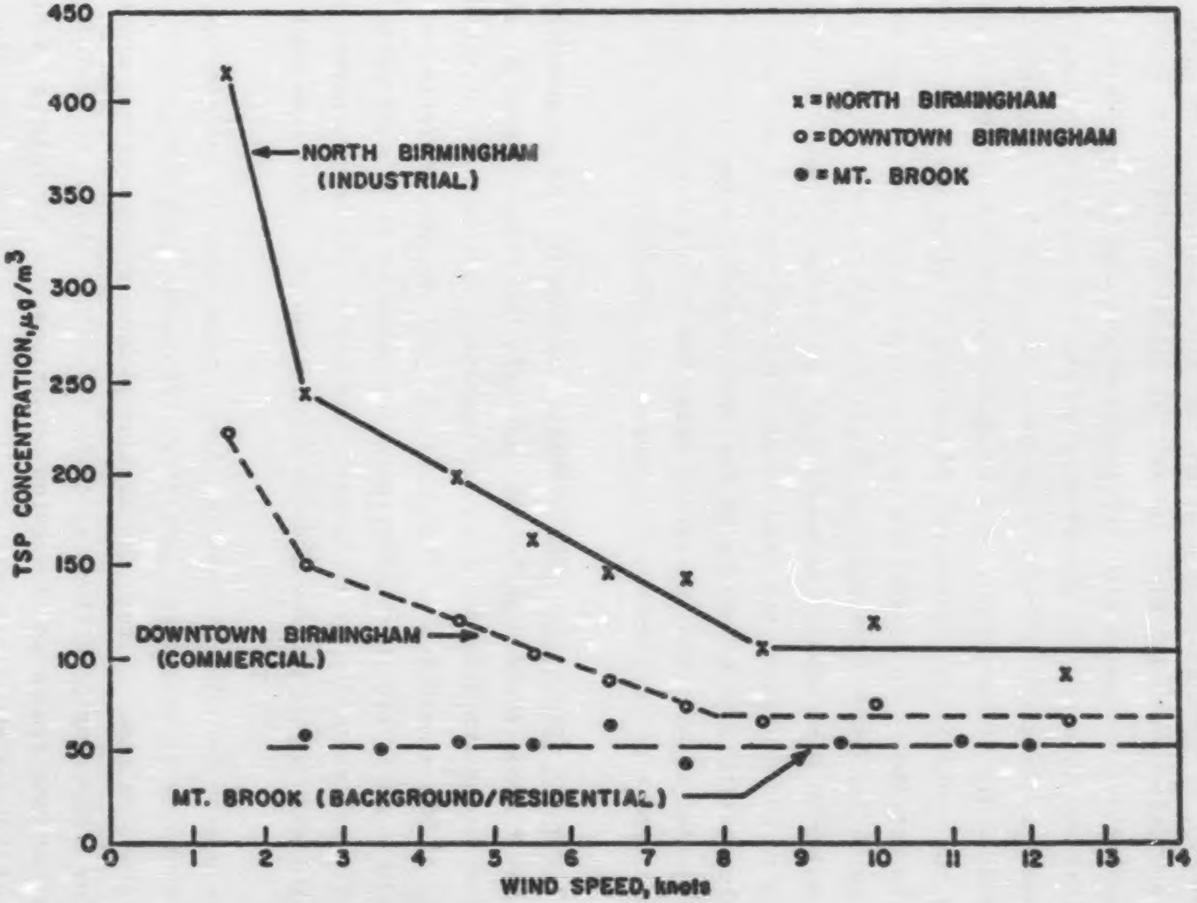


Figure 15. Relationship between TSP concentrations and wind speed at three selected sites in Birmingham on days with 48-hour precipitation amounts ≤ 0.02 inches

part of the country with the maximum number of stagnations as defined and determined by Korshover (see Reference 10, Appendix F), stagnations occur on an average of 3.8 percent of the days in a year. If on these days the average concentration is 2.3 times the annual mean, the increase in the annual mean due to the stagnation days is approximately 5 percent.

Temperature — Temperature, and seasonal temperature patterns, are the best single indicators of space heating requirements, and hence correlate with particulate emissions from these sources. Emissions from city to city for the same number of degree days will vary with the type of fuel burned. Temperature also plays a part in fugitive dust emissions by affecting the evaporation rate of water and by its influance on the growth of vegetation.

The impact of temperature (using heating and cooling degree days) was investigated in each city and the results are reported in the individual volume for the city. Comparisons among the various cities were made using a regression analysis, reported later in this section. (Also see Appendix F.)

Wind Direction — On a local scale, the wind direction determines the polar distribution of pollutants around their sources, and hence is requisite to the understanding of source-receptor relationships and the design of source-specific sampling networks. On a regional scale, the TSP concentration in the air mass entering an urban area is determined by the past history of the air mass, which is best estimated by trajectory calculations; wind direction roses can also be helpful. While wind direction-pollution roses were calculated and reported in many of the city volumes, trajectory analysis was done for only one case; that analysis is given in Appendix C.

Solar Radiation — In addition to being the driving energy source for weather systems, solar radiation relates to particulate emissions through temperature, evaporation, and plant growth. Solar radiation can also increase the ambient TSP levels by providing the requisite energy for the conversion of gases to secondary particulates.

Combined Impact of Meteorology

Multiple regression analysis was used to estimate the effects of annual variations in meteorological parameters over the 5-year period from 1970 to 1974 on the annual mean TSP levels in the study cities. The three meteorological parameters initially considered as independent variables were precipitation, temperature (heating degree days), and wind speed. After initial calculations, plus reflection on the apparent lack of short-term correlation between wind speed and TSP level except in industrial areas, it was decided to exclude wind speed from the analysis. Allowance for a linear trend was made by designating 1970 as year 1, 1971 as year 2, and so on.

In the analysis, each site type average in each city was treated as a separate observation. Dummy variables were used to permit different intercepts for the several cities and the three site types, while the meteorological effects were estimated based on data from all cities. This approach in effect assumes that the meteorological parameters operate in roughly the same manner throughout the country, which is clearly neither an obvious nor a trivial assumption. Previous analyses that permitted the meteorological effects to differ from city to city did indicate that the effects found in the various cities were quite similar in magnitude, and it is on this basis that the assumption was made.

The resulting equation was:

$$TSP = C - 2.9Y - 0.43P + 2.5T$$

where TSP = annual geometric mean concentration in $\mu g/m^3$

C = constant in $\mu g/m^3$

Y = year, 1 to 5

P = annual precipitation in inches

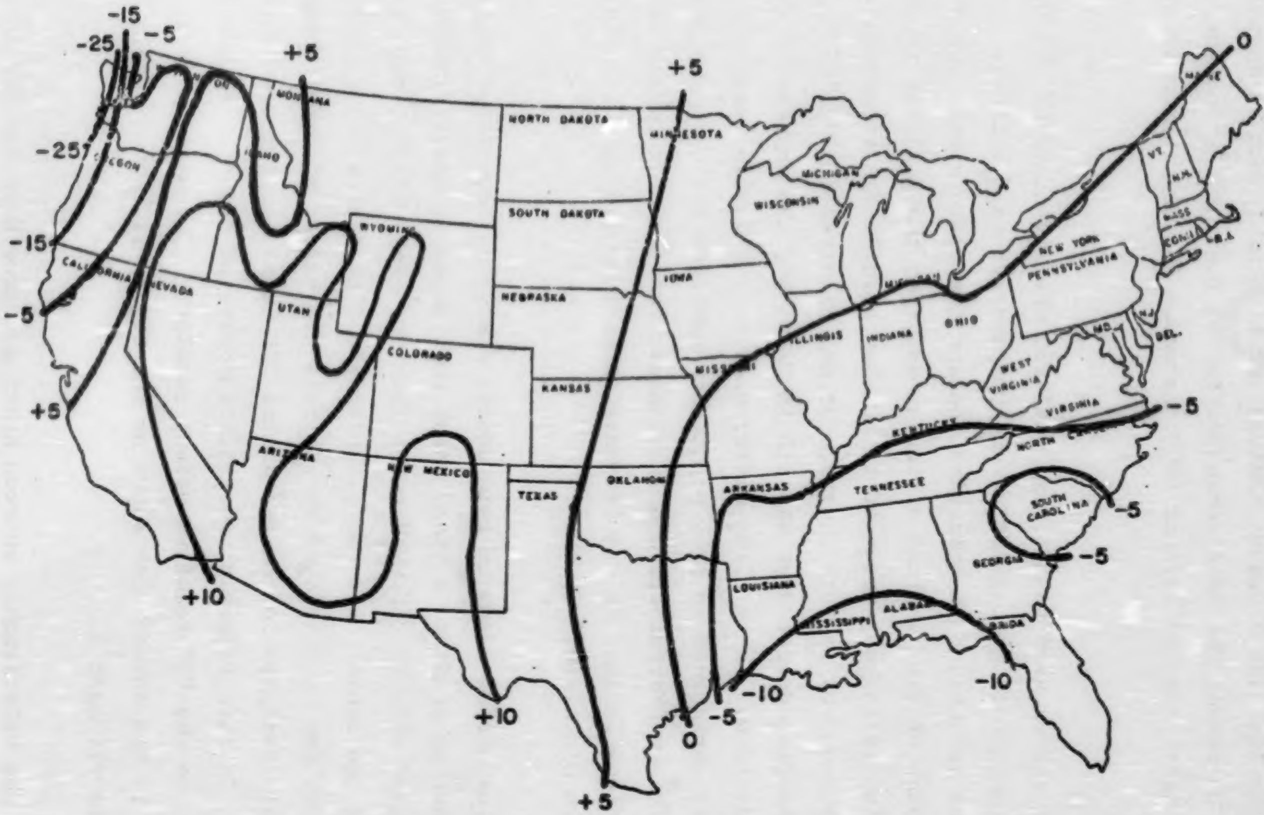
T = heating degree days in thousands.

The implication of the general regression equation is that within the study cities concentrations have been lowering at the rate of 2.9 $\mu g/m^3$ per year over the last 5 years, that an increase of 1 inch in annual precipitation decreases the mean concentration by 0.43 $\mu g/m^3$, and that an increase in heating degree days of 1000 increases the mean concentration by 2.5 $\mu g/m^3$.

This result can be used to get some feel for the magnitude of the effects of annual changes in precipitation and temperature on TSP levels. Examination of the variations in precipitation and temperature over the 5-year period in each of the 14 study cities showed that the smallest range in precipitation (6 inches) occurred in St. Louis while the greatest range (27 inches) occurred in both Chattanooga and Providence. The minimum range for heating degree days was 188 in Miami and the maximum range was 1189 in Cleveland. The implied differences in TSP levels resulting from these annual variations in precipitation range from 2.6 $\mu g/m^3$ in St. Louis to 11.6 $\mu g/m^3$ in Chattanooga and Providence, and the differences resulting from variations in heating requirements range from 0.5 $\mu g/m^3$ in Miami to 3.0 $\mu g/m^3$ in Cleveland.

Although conclusions based on this equation must be considered tentative, the relationship provides a ready means for comparing precipitation and heating demand effects throughout the country. For example, the results of applying the equation to the climatological precipitation pattern (Figure F-20) can be displayed as the relative effect of differences in total annual precipitation on the annual TSP level, as has been done in Figure 16. In this figure a precipitation rate of about 35 inches a year corresponds to the "0" relative effect isopleth. The maximum geographical difference in the annual mean shown by the figure is approximately 35 $\mu g/m^3$ (from -25 to +10 $\mu g/m^3$).

The use of the relationship between heating degree days and TSP level in conjunction with the geographical distribution of degree days shown in Figure F-27 suggests a maximum contribution to the annual mean from space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GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
MD.
N.J.
DEL.
VT.
N.H.
MASS.
CONN.
R.I.
MAINE

Figure 16. Relative effect of annual precipitation on annual TSP level in a hypothetical urban area. (Estimated from regression equation, p. 100)

heating of 25 $\mu g/m^3$. The spatial variation in degree days found in the western United States has been drastically smoothed out in Figure F-27, so attention should really be focused on the area east of the Rockies. The effect of space heating on TSP levels ranges from about 5 $\mu g/m^3$ in the southern tier of states to 22 $\mu g/m^3$ in the most norther states. Again, this is an attempt to generalize the effect of space heating using data from a mix of cities with widely different fuel usage characteristics, and the results therefore are not necessarily appropriate for any specific city.

Conclusions

Low TSP levels are to be expected in a "standard" urban area if it is located in a generally flat, well-exposed topographical setting where:

- Entering air is clean (i.e., nonurban levels are low).
- Annual precipitation is high and distributed throughout all months of the year. (Moderate amounts of precipitation roughly every third day are very effective in cleansing the atmosphere and in suppressing fugitive dust.)
- Wind speeds are not extreme. (Light winds minimize dilution, and strong gusty winds generate fugitive dust under dry conditions).
- Daytime mixing depths are high and the frequency of low-level inversions is low. (This combination maximizes periods of good vertical daytime dispersion and minimizes periods of poor nighttime dispersion.)
- Space heating demands are minimal. (With a standard mix of fuels, space heating emissions are proportional to degree days.)
- High-pressure weather systems do not stagnate. (Stagnant anticyclones with accompanying light winds, a persistent subsidence inversion, and nocturnal surface-based inversions lead to accumulated high TSP concentrations and violations of the 24-hour standards.)
- The frequency and character of winter precipitation is such that street sanding is rarely, if ever, required. (On the other hand, snow cover is highly effective in eliminating fugitive dust.)

Conversely, high TSP concentrations are to be expected in a "standard" urban area if air entering the city already contains a substantial particulate loading, and if the location is sheltered with resulting poor ventilation, has a cold, dry climate, and experiences frequent stagnant high-pressure systems.

Because of complex interrelationships among meteorological parameters and the generation, transport, dispersion, and depletion of airborne particulates, however, it must be recognized that a single parameter may bring about opposing effects and, further, that certain meteorological parameters tend to be linked by the nature of typical weather systems: fast moving air dilutes and transports pollutants readily but also increases evaporation, thus hastening the drying of soil and settled particulates, and as a consequence the air stream may entrain particulates from the dried surfaces; high temperatures increase evaporation, but also encourage the growth of vegetation and eliminate the need for space heating; snow and ice eliminate fugitive dust emissions from most surfaces, but may result in the need for extensive street sanding and hence ultimately be responsible for an increase in urban fugitive dust emissions.

While it is possible to make certain judgments based on what are believed to be the major effects of precipitation, heating degree days, and stagnation periods as done above, only a rigorous statistical analysis can properly assess the effects of meteorological and climatological parameters on nationwide urban TSP levels. Such a study was beyond the scope of the present effort, and any serious attempt to assign a TSP pollution potential rating to individual AQCRs should await the completion of such an analysis.

RELATIVE CONTRIBUTIONS OF VARIOUS FACTORS

By way of summary, the following discussion considers the overall average ambient TSP level and divides it into portions considered representative of the influences of the various major factors discussed in this section.

Such an analysis is essentially a mnemonic device, averaging over many important variables. Consequently, it should not be interpreted quantitatively with respect to any particular site or urban area; a discussion concerning how these results may be particularized to specific conditions is presented in Appendix G.

The contributions to the overall particulate level at any point have been classified as coming from three major categories — emissions from traditional sources, emissions from nontraditional sources, and nonurban particulates. In addition, two major categories of modifying influences were identified - meteorological factors and monitoring considerations. The rough qualitative impact of these factors was suggested in the sketch in Figure 3 in Section II. The following quantification of those factors is built around Figure 17.

Nonurban Levels — The most basic contribution to the total is roughly 30 $\mu g/m^3$ of natural and transported particulates. As discussed above, and as seen in the small bar chart to the side in Figure 17, this level varies significantly among various regions of the continent. The low west coast level of about 15 $\mu g/m^3$ represents the favorable situation of being located on the ocean and receiving air with essentially globally averaged natural TSP levels. The mid-continent level of about 25 $\mu g/m^3$ includes a 10 $\mu g/m^3$ increments, representing a slight increase in secondary particulates (1 to 2 $\mu g/m^3$) and a major contribution from the natural particulates accumulated as the air mass passes over the broad, relatively dry, western portion of the continent.

The northeastern nonurban levels then contain a further 10 $\mu g/m^3$ increment, which consists of two major pieces. A significant increase in transported secondary particulates, the precise source of which is not thoroughly proven, is a large share of the increment. The other share is attributed to transported primary particulates from the major urban concentrations of the midwest and northeast.

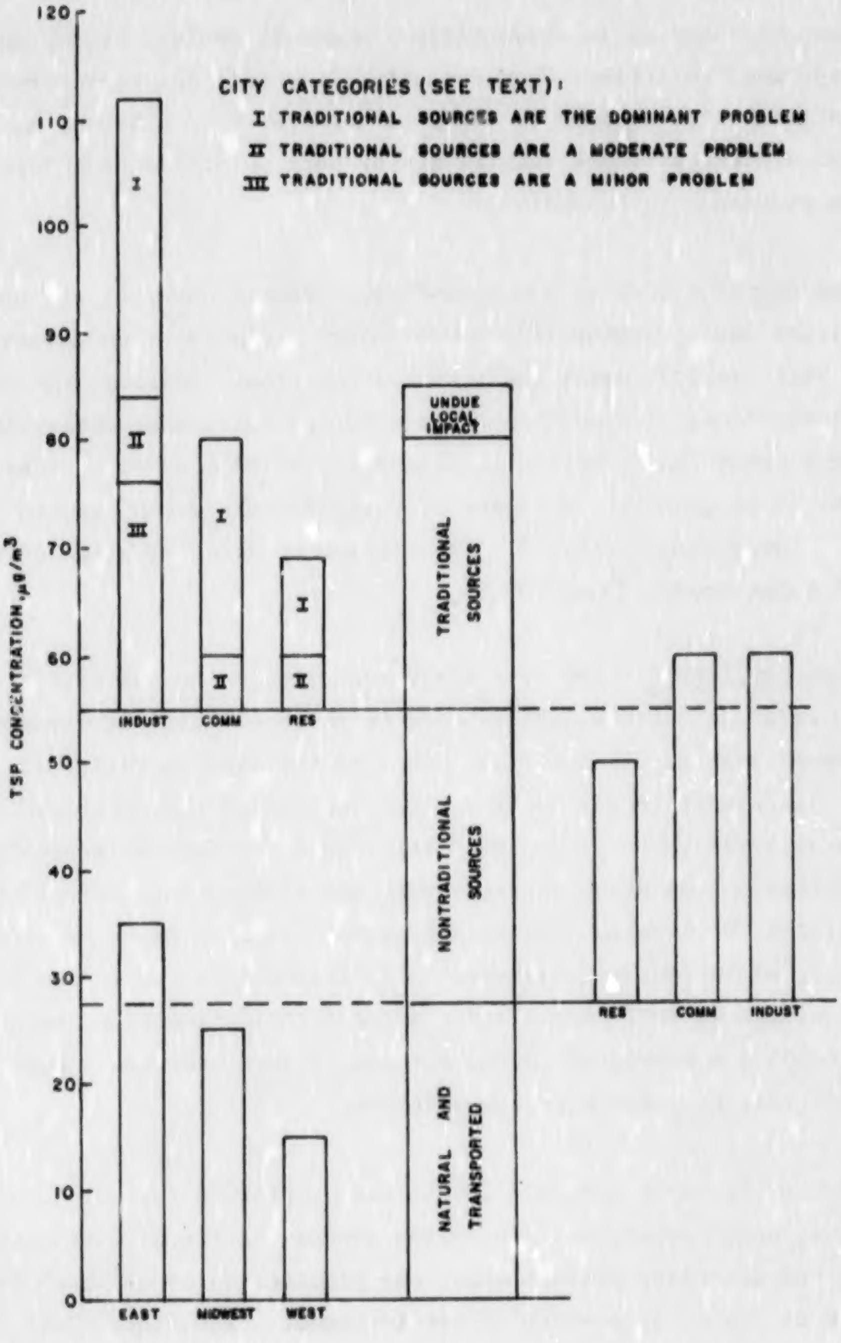

Figure 17. Summary of average impact of major contributors to TSP levels

Emissions From Nontraditional Sources - The general types of nontraditional sources identified as important are essentially the substance of human activity in urban areas. They occur in every urban area and hence are seen as more basic than the traditional sources, which are of only minor concern in at least some urban areas. The overall contribution from such sources, however, differs significantly among different neighborhoods within a single urban area, as seen in the small bar chart in Figure 17. This contribution, which consists primarily of the effects of tailpipe emissions, tire wear, and road dust reentrainment, is about 20 $\mu g/m^3$ in residential areas and about 30 $\mu g/m^3$ in commercial and industrial areas, the difference being the greater level of traffic. The proportion of residential versus other sites considered in averaging over the other two categories is a matter of abstract philosophy; an average of roughly 25 $\mu g/m^3$ has been selected for use in the figure.

Emissions From Traditional Sources - The third major contributor to ambient levels— traditional sources— varies dramatically not only with neighborhood type but also with the general industrial nature of the city. As was seen in Figure 9, the impact of traditional sources can range up to about 10 $\mu g/m^3$ and 30 $\mu g/m^3$ at residential and commercial sites respectively, and up to 50 $\mu g/m^3$ at industrial sites. This latter figure reflects the inclusion of fugitive emissions from industrial sources, but the contribution of truck traffic and similar industry-related emissions has been included with nontraditional sources. Roughly averaging over various neighborhood types and over the spectrum of nonindustrial to heavily industrial cities, a value of 25 $\mu g/m^3$ has been included in Figure 16.

This addition of 25 $\mu g/m^3$ is the same as the contribution from nontraditional sources; thus on a nationwide basis, the two categories are roughly equivalent. However, it must be kept in mind that the differences among cities affects this balance significantly.

Modifying Factors - The two major categories of modifying factors are not so readily represented graphically. Meteorological and climatological factors primarily can increase or decrease the average levels depending on the various regions of the country. Quantitatively, the effect is fairly commonly about 5 $\mu g/m^3$, and in some areas 10 $\mu g/m^3$.

The influence of monitoring considerations comes primarily in distorting comparisons of measured levels among neighborhoods and cities. However, the aggregate nationwide average of undue influence from nearby sources can add a very few $\mu g/m^3$ to the total, as indicated in Figure 17.

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SECTION IV

SUMMARY AND CONCLUSIONS

This section summarizes the findings of the study, including the study approach to general problem assessment, the attainment factors identified, the assessment of these factors, the control options available, and their applicability and priority for control.

This study approached the national particulate problem with many of the same tools an individual air quality planner would use to approach an assessment of the problem in a particular urban area. It utilized air quality data analysis, emissions data and modeling, and analytical particle identification; these, along with special monitoring studies, are the techniques with which a TSP problem at any level is studied. However, the results of this study are intended to provide general information on a national scale rather than urban-scale planning information for the 14 study cities or any others. While the individual air quality planner will hopefully find the results useful, they are not intended to solve any specific problems in specific urban areas. Rather, the results provide an additional component of technical information which will need to be integrated and assessed in conjunction with local knowledge.

ATTAINMENT FACTORS IDENTIFIED IN CITY STUDIES

The purpose of the city case studies was to identify and study the various factors, problems, and issues concerned with attaining the TSP standards as they were experienced in each city. Since the 14 cities cover a broad range of city characteristics and hence represent a variety of situations with respect to TSP air quality and its determinants, analyses of the factors in the various cities can be drawn together for an overall assessment of the TSP attainment situation in the study cities and, by extrapolation, throughout the nation.

Following the analyses of the study cities, a number of factors were identified as significant for standards attainment. Many of these had been first identified in the preliminary literature review and were then followed up in the city studies; a few others were identified in the course of one or more of the city studies. These issues are listed below, grouped into categories that provide a framework for discussions.

Traditional Factors

Air pollution programs have traditionally been oriented toward the control of fuel combustion, process emissions and incineration. Such control programs have resulted in substantial reductions in emissions and corresponding improvements in air quality in many of the 14 study cities.

While all of the cities studied have ongoing control programs for traditional sources, there were differences both in the amount of traditional source influence and in the success of the program:

- Three cities still have significant problems with traditional sources. Citywide air quality averages are typically 30 $\mu g/m^3$ higher than they are in similar cities with light emissions from industry and fuel combustion.
- Three cities have had heavy industrial sources and problems, but have made major improvements in air quality. They still, however, have citywide averages typically 10 to 15 $\mu g/m^3$ higher than similar cities with light emissions. There is some potential for improvement in air quality in these cities by further reduction of traditional sources.
- Four cities have had moderate emissions problems and have them well under control. These cities must control nontraditional sources to make further, substantial improvements in air quality.

- Four cities never had problems with traditional sources, except fuel combustion for heating and power generation. Further improvements must come from control of nontraditional sources.

The major sources still presenting problems with attainment of standards are in the primary metals and minerals industries. Of primary concern are the fugitive emissions which are not confined and do not come from a stack or vent. These emissions have substantial impact on air quality; sites which were influenced by fugitive emissions averaged 25 $\mu g/m^3$ higher than industrial sites affected by stack emissions only. This is partly due to the typically low level emission point and poor potential for dispersion. Another problem is that of area source fuel combustion; fuel oil is estimated to contribute on the order of 5 to 10 $\mu g/m^3$ to citywide averages in cities where oil is a primary fuel. A similar order of impact is realized from the many small (minor) sources if these sources are generally uncontrolled.

Major program considerations which were determined to be a factor in traditional source impact are the assurance of compliance with existing regulations and, in some cases, the stringency of those regulations. This will be discussed further under control alternatives.

Nontraditional Factors

While many cities have realized substantial improvements in air quality, few cities have all sites below the primary standard and fewer still have all sites below the secondary standard. This is due to the impact of factors which have not been traditionally addressed by the air pollution programs, such as reentrained dust, tire wear particles, dust from construction, and automotive exhaust emissions. The impact of all such general urban activity varies from a typical impact of 20 to 25 $\mu g/m^3$ in residential areas to a typical impact of 30 to 35 $\mu g/m^3$ in commercial and industrial areas; the citywide contribution is about 30 $\mu g/m^3$. The components of this contribution are discussed below.

- Reentrained dust— The impact was found to vary with the traffic flow and inversely to the height and distance of the monitor from the street. The average impact on residential monitors is estimated at 10 to 15 μg/m^3 and 15 to 20 μg/m^3 at commercial and industrial sites respectively. The composition of this component is mostly mineral matter.

- Tire rubber particles— This component of nontraditional particulates is even more variable with neighborhoods. Typical impacts of 2 to 5, 5 to 10 and 3 to 7 μg/m^3 were found at residential, commercial and industrial sites, respectively. Sites located particularly near heavy traffic averaged twice the levels at other sites.

- Construction — Impacts of 15 μg/m^3 are common only if the construction is close to the monitoring site. Cities with typical levels of construction have citywide impacts on the order of 1 to 3 μg/m^3.

- Automotive exhaust — This varies somewhat with neighborhoods, with concentrations of 3 μg/m^3 in residential and 4 to 5 μg/m^3 in commercial and industrial areas. This estimate is for the primary particulate only and is generally about 20 to 25 percent lead.

Large Scale Factors

Large scale factors are the combined influences of particulate matter that dominate an area much larger than the urban areas being studied. They include natural particulates and transported primary and secondary particulates. These factors, in affecting the TSP levels in an urban area, can cause significant differences in the controllability of the TSP problem. Their effect on urban levels is generally estimated by measuring air quality in nonurban areas. The average nonurban particulate level for the 14 study cities is between 25 and 30 μg/m^3; however, values ranged from less than 15 μg/m^3 on the west coast to over 35 μg/m^3 in the densely metropolitan east.

Transported secondary particulates make up a significant portion of nonurban levels. Nonurban sulfate and nitrate levels range from very low in the midwest and west to around 10 $\mu g/m^3$ in the northeast. Total urban secondary levels vary up to around 15 $\mu g/m^3$ in the north and east.

Other Related Factors

In addition to the above factors, which are to varying degrees related to sources of emissions, other factors were found to affect the real or apparent TSP problem. As discussed in the selection of the cities, the meteorology and climatology of a region can help to aggravate or ameliorate the TSP problem; the dispersion characteristics and precipitation levels are the most prominent influences. The design of the monitoring network and the actual placement of monitors is also important in conceptualizing what the TSP situation is. The general findings from the city studies for these factors are summarized below.

- Monitoring considerations — The siting practice of the control agency has considerable impact on the air quality levels and number of violations recorded. For example, 10 of the 60 commercial sites visited had local impacts from nearby sources. With one exception, all these sites violated the primary annual standard. Also, since industrial neighborhoods were shown to have substantially higher TSP levels, the proximity of monitors to industrial neighborhoods is an important variable. A specific relationship was found in the study between average daily traffic (ADT) at a site, the slant distance of the monitor from the street, and air quality levels. For example, based on approximate calculations, a monitor 100 feet (slant distance) from a busy street (10,000 ADT) might be influenced by the reentrained dust, tire wear and exhaust by 10 $\mu g/m^3$. This same relationship shows an impact of 40 to 45 $\mu g/m^3$ if the monitor is only 25 feet from the street.

- Meteorology — The study found precipitation to be an extremely important variable; a yearly increase in rainfall of 1 inch can cause decreases in citywide annual averages of 0.4 $\mu g/m^3$. It also concluded that average windspeeds above 10 miles per hour could cause some resuspension of dust. The effect on air quality would depend upon the gustiness of the wind and the condition of the soil.

CONTROL STRATEGY OPTIONS

The development of a control strategy for the attainment and maintenance of the ambient particulate standards must depend on accurate identification of the sources responsible for the particulate problem. Once this identification has been established, the available control measures can be defined, evaluated, and combined into an aggregate control strategy which is appropriate and effective. The major single conclusion of the study is that the control measures traditionally directed at pollution sources are not going to be adequate in many cases, and that other, more novel control measures directed at nontraditional sources and sources contributing to nonurban levels must also be considered.

Proposing detailed control strategies or priorities for specific situations is beyond the scope of this study. Such a process must necessarily involve the addition of significant quantities of local knowledge. Nonetheless, two points should be mentioned briefly. The first involves the relative emphasis on the three main contributions to urban TSP. If traditional sources still contribute the major share of TSP in an area, they are clearly the most appropriate segment to attack. Potential overall reductions in emissions of 75 percent or more may be expected in those cases where sources are not yet stringently controlled. In every city, industrial or otherwise, the nontraditional sources present a more difficult target, with reductions of 50 percent or less probable even from truly extensive control efforts. The nonurban contributions, which are a major influence in at least the nonindustrial cities, are the worst in the sense of being essentially intractable at a state and local scale. The priorities for control must consider these general differences. The second point to remember when selecting among strategies is that there are a number of considerations other than simply mass particulate reduction.

Keeping in mind the need for individual consideration in each area violating the TSP standards, the following discussion lists the types of control measures generally considered appropriate for each of the various sources of particulates included in the three major categories previously outlined.

Control Measures Directed at Traditional Sources

The general pattern of control technology applicable to traditional sources is well established; the open questions are primarily those of application. In this sense, it is appropriate to subdivide the category of traditional sources into four subcategories:

- Major point sources
- Smaller point sources
- Fugitive emission sources
- Fuel combustion area sources.

Stack Emissions - With some differences in emphasis, the control measures available for both major and smaller point sources are similar.

- Obtain compliance with regulations - existing efforts to bring sources into compliance must continue, and must be extended in those areas where current efforts are incomplete.

- Tighten compliance determination and surveillance procedures - one area of significant difference by size of source; major sources should be stack tested at least annually, smaller sources inspected frequently under a tight surveillance system.

- Tighten regulation stringency - after considering carefully the local need for tighter traditional source control:

  - Upgrade regulations for selected major sources and smaller sources to at least require the best control technology reasonably available (not necessarily RACT as currently promulgated).

  - Incineration can be completely banned in favor of landfilling or shredding for power generation.

  - Process losses covered under a general process weight regulation can be further restricted by adopting regulations specific to individual problem industries.

Fugitive Emissions - Aside from the major concerns of improved surveillance and enforcement, specific measures for reducing fugitive emissions from traditional sources include special regulations beyond simple nuisance or "reasonable precaution" regulations:

- Quantitative or visible emission standards at property lines
- Operating and maintenance standards for specific processes
  - Covering storage piles
  - Enclosing materials handling equipment
  - Paving roadways and loading and parking areas

Area Source Fuel Combustion - Though difficult to effectively control because of their large numbers, there is a real possibility of reducing emissions from such sources, if the need warrants, through measures such as the following:

- Design standards for new boilers
- Maintenance of oil boilers
- Prohibition of coal use
- Inspection and maintenance of small oil burners

Control Measures Directed at Nontraditional Sources

Concurrent with taking the appropriate steps to control traditional sources, and in areas where traditional sources have never been the major problem, control strategies for the attainment of the TSP standards may have to consider control of those nontraditional sources discussed in Section III. Implicit in the very label "nontraditional" is the concept that these sources have not had control measures directed at them. However, control of these sources is not so much a matter that is beyond reach technically as it is a matter of using measures that are costly or hard to justify or, in many cases, simply measures that are not normally seen as pollution control measures. Examples of these types of measures are listed below for the three major categories of such sources:

- Motor vehicle exhaust
- Fugitive dust from construction and demolition operations
- Reentrainment of particles from roadway surfaces.

Motor Vehicle Exhaust - In urban areas where tailpipe emissions are found to be contributing 5 to 10 $\mu g/m^3$ to the total suspended particulate loading, it may be necessary to consider their control. The available control measures for lowering tailpipe emissions are:

- Reduce lead in gasoline
- Reduce VMT totals in area
- Reduce emission per mile through inspection and maintenance
- Particulate control devices on cars.

Construction/Demolition and Other Fugitive Dust Sources - The control of dust from construction and demolition activities and similar activities is most often approached through the use of nuisance or reasonable precaution regulations much as is the case with fugitive emissions. More specific control measures that can be applied include:

- Watering construction site and demolition rubble
- Chemical soil stabilization
- Use of sequential blasting demolition.

Reentrained particulates - The majority of such particulates are street dust entrained by traffic; control measures include both preventive measures and street cleaning:

- Control of dust deposition - A viable approach to controlling reentrained particulates is reducing the amount of particulate matter available for reentrainment; control measures include:
    - Fallout - The fallout level will decrease automatically with control of traditional source emissions.

  - Carryout - Dirt and mud carryout from unpaved roads and parking lots can be reduced by requirements for paving or stabilization of these areas.
  - Spillage - The loading on streets due to spillage from trucks is easily regulated against, but enforcement may be a problem. Regulations that require specific equipment on trucks would probably be an improvement.
  - Tirewear Particulates - Reduction in the amount of rubber tire particles could be effected by VMT reduction or by designing and requiring tires with better wear characteristics.
  - Sanding - Because of the obvious hazard of slippery roads, sanding and salting operations will obviously continue. Analysis of the efficiency of sanding may result in procedures that apply less sand more effectively; however, systematic road cleaning after sanding operations would be more appropriate.

- Street cleaning to remove deposited material - Since it is not possible to prevent all deposition of particles on a paved surface, an alternative or auxiliary approach to control of particle reentrainment is to remove the particles from the surface. Control measures include:
  - Street cleaning
    - Rotating broom sweepers
    - Regenerative air blast sweepers
    - Vacuum street cleaners
  - Street flushing with water.

Control Measures Directed at Transported Primary and Secondary Particulates

A complicating factor in any standards attainment strategy development is the concentration of TSP in the incoming air mass. When such concentrations approach or exceed the standards, there is little if anything that an agency can do to meet the standards unless the controls are also pursued for this incoming (nonurban) TSP. Obviously, there are really no appropriate measures for the contribution of natural sources to these TSP levels; however, those particulates directly attributed to man's activities are, to varying degrees, controllable. In certain cases attention directed toward control of these sources may be more profitable than nontraditional control techniques.

Transported Primary Particulates - Those particulates that are emitted directly as primary particulates and are then transported from one area to another can be controlled through conventional traditional source regulations. The difficulty arises in the development of regionwide control strategies in which one area may need to limit its emissions more severely than necessary to simply meet the standards in that area because of the impact on a neighboring area. Such regionwide planning may be immediately possible on a statewide basis or may require interstate and inter-EPA region cooperation.

Secondary Particulates - Much the same thing can be said for secondary particulates except that many of the secondary particulates are formed in transport over much longer distances than would normally be of concern for primary particulates. Therefore, these control strategies must seek national direction rather than state or interstate cooperation. However, secondary particulates that are locally formed can presumably be locally controlled. As indicated in Section III, urban excess secondary particulates may add 5 $\mu g/m^3$ to levels in the city and these particulates could be controlled once the appropriate precursor relationships are known.

FRAMEWORK FOR CONTROL STRATEGY PRIORITIZATION

The institution of control measures must be preceded by the careful prioritization of available options. This section suggests a framework for evaluating control options as a function of the scale of the problem. There are significant differences in the general prevalence of the three major factors — traditional sources, nontraditional sources, and large-scale consideration — and thus the applicability of their associated control options, when dealing with problems of different geographical scales.

Consequently, priorities for instituting control options are best made within this context of differing scales.

Concept of Scale

A general assessment of the relative scale of impact of the factors affecting attainment can be made. It is helpful to think of TSP problems as affecting either a relatively small area (neighborhood), an entire urban area, or many urban areas in a general region (intercity). These are discussed below.

- Neighborhood scale - TSP problems over areas a few blocks in size occur even in the urban areas with relatively low citywide levels; typically measured by only one hi-vol, these problems are often caused by a relatively local source, frequently a small industry or fugitive dust source. Major sources are seen as less of a problem on the neighborhood scale due to the tall stacks providing good dispersion.
- Urban scale - In some urban areas, the TSP problem is to a large extent citywide (in addition to neighborhood hot spots), and is less likely to be due to a relatively few indentifiable sources as on the neighborhood scale.
- Intercity scale - In some portions of the country, there is a general regional TSP problem that transcends any individual urban area or AQCR.

Within any particular area, it is very possible to have problems in all three of these scales simultaneously. Nonetheless, the overall control approach to each can be generally independent and in fact, problems of certain types typically occur primarily in one geographic scale. For example, nontraditional sources typically cause mostly neighborhood problems, while traditional sources may more likely cause urban-scale problems.

Priorities of Instituting Control Options

The previous sections have delineated various control measures that could be instituted by agencies and suggested the general scale of applicability of different factors affecting attainment and their associated control measures. This section suggests the specific categories of sources for which control measures could be applied to reduce particulate concentrations at each level or scale. The source categories into which the many types of air quality problems have been generalized are as follows:

- Traditional
  - Major sources
  - Small sources
  - Fugitive emissions
  - Area source fuel combustion
- Nontraditional
  - Resuspended dust from roadways
  - Fugitive dust from construction and demolition
  - Auto tailpipe emissions
- Large scale
  - Transported primary particulates
  - Transported secondary particulate
  - Urban secondary excess

The following matrix (Table 16) summarizes the priorities for adopting control measures for these categories of sources as a function of the scale of the problem.

Table 16. CONTROL PRIORITIES

Order of priority	Regional scale of problem			
		Urban		
	Neighborhood	Lightly industrialized	Heavily industrialized	Intercity
1	Fugitive emissions Reentrained dust Fugitive dust/ construction	Reentrainment dust Auto tailpipe Area source fuel combustion	Major sources Urban secondary Small excess sources Fugitive emissions	Major sources Transported primary Transported secondary
2	Small sources Area source fuel combustion Auto tailpipe	Urban secondary Small excess sources Fugitive dust/ construction	Reentrained dust Auto tailpipe	Small sources Area source fuel combustion
3	Urban secondary excess Major sources	Major sources	Area source fuel combustion Fugitive dust/ construction	Fugitive emissions Reentrained dust Fugitive dust Auto tailpipe

SECTION V

RECOMMENDATIONS

The broad scope of this study provided an opportunity for an evaluation of the control practices to date, as assessment of the controls that are needed in the future, and an understanding of the obstacles that are preventing the attainment and maintenance of the NAAQS for TSP. Based on these findings, numerous recommendations have been formulated. The recommendations cover a wide range of topics and are directed at various audiences both inside and outside of EPA. Some of these recommendations are readily apparent from this study and are, in fact, called out separately, as in Appendix G. Others are the result of integrating all the findings and analyses conducted over the course of the study with the literature reviewed and the discussions with federal, state, and local control officials.

The recommendations provided below run the full gamut of considerations. They are organized by first presenting specific recommendations for emission control efforts, then more general recommendations concerning the major upgrading of quantitative air quality management planning, and finally recommendations regarding the current review and further development of the NAAQS for TSP.

In general, all of these recommendations recognize the need to provide appropriate justification for any new major control approach that must be adopted. Equally important is the demonstration that proposed control programs will result in the necessary improvements in air quality.

RECOMMENDATIONS FOR EMISSION CONTROL EFFORTS

The following recommendations are grouped for convenience into three groups corresponding to the three major components of urban TSP levels as discussed previously— traditional particulate sources, nontraditional sources, and nonurban particulate levels.

Control of Traditional Sources

All urban areas do not require an equivalent degree of traditional source control. The first set of recommendations presents control efforts considered appropriate for major industrialized urban areas having an apparent TSP problem primarily associated with emissions from major fuel combustion, industrial process and solid waste operations. The second and third set of recommendations are directed at all urban areas, both those that are heavily industrialized and those that have only a moderate to light amount of industry and area-wide combustion of oil or coal. Such a breakdown presumes that most of the effective programs will already meet the first set of recommendations for local control planning. However, additional control may still be needed under large scale planning efforts as discussed later.

1. Control of Major Point Sources

   a. Limitations on emissions from fuel-burning installations of all sizes should be tightened considerably. There is a factor of at least 4 between the typical regulation and the most stringent, yet workable, regulation; while very stringent requirements are likely not required in many urban areas, in major industrial areas they are clearly needed.

   b. Emission limitations applicable to major oil-burning installations should be defined separately, and more stringently, than those applicable to coal combustion. A single, uniform combustion regulation that was designed to permit some coal combustion will unavoidably permit relatively poorly controlled residual oil combustion, simply because of the inherently different emissions potential of the two fuels. There is no need for this, nor for the attitude that coal-to-oil conversion should be seen as a total abatement of the source; oil-fired sources can and should be controlled.

c. All major combustion sources that have undergone coal-to-oil conversion should be tested. There are significant differences in effectiveness when control devices designed for coal fly ash are utilized on oil-fired units, yet it appears not uncommon for the original percent-efficiency figures to be utilized in calculating emissions levels.

d. Emissions from industrial process losses should be regulated on the basis of industry-specific restrictions. The present common practice of utilizing a general process-weight curve necessarily means that relatively-easy-to-control processes will only be required to meet such standards as are appropriate for the more difficult to control ones. Major processes in any given area should be regulated with a specific emission limitation economically and technologically tailored to that industry.

e. Compliance determination procedures in general should be significantly strengthened, primarily by increased use of source testing and source surveillance. In general, the degree of assurance of stated control efficiencies, etc., appears to be less rigorous than needed to provide good quantitative compliance knowledge. While it is *not* recommended that all sources be physically tested, it is believed that a much greater level of testing is needed than is now practiced. All large sources and all unique sources should be tested on compliance attainment and at intervals thereafter, either by agency personnel or by an approved independent testing organization. Reliance on routine engineering calculations should be permitted only for the simplest, most routine situations. Source tests should take care to include not only stack emissions but fugitive emissions from processes. Systematically and randomly scheduled visits should be made with schedules depending upon the source size, history of complaints and problems, and compliance status.

2. Control of Fugitive Emissions

a. EPA should develop and make available an accurate methodology for inventorying the emissions and estimating the air quality impact in the vicinity of isolated sources of fugitive emissions, such as quarries and rock-crushing operations. In order to include such emissions in air quality management planning, more adequate information must be developed.

b. In every heavily-industrialized area, the cognizant state and local agencies should conduct, and EPA should support, a major survey effort to identify and inventory fugitive emission sources. Such surveys should include field monitoring, extensive inspections of industrial premises, and the rough estimation of emission quantities. While fugitive emissions from generally-isolated industrial operations (such as quarries) are relatively easy to identify, if not quantify, it is not easy to define the degree to which fugitive emissions from dense heavy industrial areas are a problem. Consequently, a serious effort to define the nature and magnitude of the problem is required prior to dealing with it.

c. Regulations applicable to fugitive emissions from industrial property should be strengthened by the itemization of specific control measures where possible and by the institution of property-line air quality limitations where required by the complexity of the area or the industrial operations involved. It is anticipated that in cases of clear-cut, obvious sources it will be more expeditious for the control agency to identify and specify the required control measures. In contrast, in more complex situations such as a major iron and steel facility, it is anticipated that it will be more expeditious to require the source to conduct property-line monitoring and be responsible for the identification and implementation of control measures on their own property so long as the control measures required as a result of property line monitoring are no less stringent than otherwise would be required.

3. Control of Small Point Sources and Areawide Fuel Combustion

a. State and local agencies should reassess their point source cutoff to ensure that a major percentage of their traditional source inventory is receiving individual attention. Arbitrary cutoff points of 25, 50, 100 tons/year are often used to define point and area sources. Commonly, those cities that have significantly reduced the emissions from major point sources have used a high cutoff point. As the emissions have been reduced, smaller sources are now of concern and should be considered individually for modeling, compliance, and enforcement purposes.

b. Regulations governing the allowable emissions from small combustion units should be promulgated or, if already promulgated, reviewed to reflect current fuel usage, fuel availability, and control technology. Many jurisdictions do not control small combustion units or allow emissions higher than necessary for a well-maintained unit.

c. Small incinerators should be banned in urban areas or should at least have permits required to ensure proper control and burning only under favorable meteorological conditions. Many cities have already taken this route with no major obstacles to its implementation.

Control of Nontraditional Sources

In contrast to the control of more conventional sources, which is primarily a problem in industrialized areas, the management of particulates arising from urban activity is likely to be required in essentially all urban areas of any size. However, nontraditional sources are not such a well-defined problem as to permit immediate and detailed control strategy planning. Rather, no major national attack on such particulate sources is considered appropriate for implementation until a variety of preparatory steps have been taken. Consequently, the following recommendations primarily concern preparation for, rather than actual implementation of, the control of urban activity sources.

1. Control of Urban Activity Sources

a. EPA should develop appropriate methodologies for inventorying emissions from nontraditonal sources in urban areas and support their proper utilization by state and local agencies. To the extent possible these inventories will take into account particle size and spatial and temporal emission rates.

b. EPA should develop and provide to the states a diffusion model which adequately takes into account the deposition characteristics and small scale diffusion of the inventoried emissions. Both short-term (24-hour) and long-term (annual) averaging models are needed which allow for variations in parameters including precipitation, ground cover, particulate loadings on roads (fluctuating with street cleaning, precipitation, sanding operations), wind speed, etc.

c. EPA should develop and implement a major effort aimed at providing, in 1 to 2 years' time, information on the costs and effectiveness of control measures potentially applicable to urban reentrainment. The effectiveness, and to some extent the cost, should be considered in light of the potential for public acceptance and ease of implementation. Cross-media environmental impacts should also be addressed; e.g., street flushing for reentrainment control.

d. EPA should develop and implement a public education effort aimed at developing recognition that nontraditional sources are of significance with respect to air quality. This effort should stress to the appropriate bodies of public opinion and governmental agencies that such sources are a legitimate subject of environmental concern.

e. State and local air pollution control agencies should begin to attack the obvious visible sources of fugitive dust such as construction, unpaved areas, etc. Some agencies already have developed programs aimed at these sources and most other agencies could control many of the sources under current nuisance regulations. Consideration should be given to requiring certain controls on specified sources.

Control of Large Scale Influences

Additional reductions in TSP levels can be expected if precursors of secondary particulates are controlled, not only within an urban area, but also "upwind" of cities. Other contributions from "upwind" sources can arrive directly via transport. Planning measures to control these contributions require national direction for implementation, but will result in a more equitable distribution of the stringency of control measures.

1. Control of Secondary Particulates

a. EPA should continue efforts to develop and document the mechanisms of formation and models for the prediction of secondary particulate levels, especially sulfates and organics, on both the meso- and macroscale. The effects of precipitation on scavenging of precursors, stagnating air conditions, insolation, thermal radiation, etc., should be adequately considered.

b. State and local agencies should take into account the formation of secondary particulates in their formulation of control strategies for TSP. The urban excess of secondary particulates must be either consciously included in the TSP level that is considered uncontrollable, thereby requiring further restrictions on traditional sources, or should be addressed through the control of the emission of precursor pollutants.

c. EPA should not permit the use of supplementary control strategies or tall stacks to satisfy immediately local air quality needs since the result may be to increase levels of secondary particulates at sites remote from the source. Because of the continental scale and variability of meteorology, it is not likely that such controls techniques would be permitted anywhere in the country. In fact, additional SO_x controls may be needed at some sites to help solve the TSP problem elsewhere.

2. Transport and Primary Particulates

a. States should require air quality planning to be done on as large a regional scale as is necessary to reach into an area not impacted by transport. Where an autonomous local agency has control over only a small part of a problem area they should have their authority extended, through a contract with the state, a regional compact, or some other arrangement.

b. EPA should support research efforts directed at the better understanding of short- and long-range transported particulates. Long-range transport under specific meteorological conditions that contribute to excessive TSP levels and cause violations of the 24-hour standards could become predictable so that appropriate measures could be taken. Short-range transport needs better documentation and analysis so that the intercity contributions to high TSP levels, leading primarily to violations of the annual standard, can be considered for air quality planning. Comprehensive inter-EPA regional planning may be necessary for TSP control.

RECOMMENDATIONS CONCERNING AIR QUALITY MANAGEMENT PLANNING

The second broad area of recommendations concerns improving the states' ability to accurately and quantitatively develop plans for the attainment and subsequent maintenance of the ambient standards. As has been noted, the general failure of the SIPs to attain the standards despite significant emission reductions is in part due to inadequate data bases and, to a less extent, to inadequate planning methodologies. This area is thus very fruitful for action, particularly short-term EPA action.

1. Development of Improved Data Bases

a. EPA should support data gathering efforts and computerized systems by state/locals which are compatible with NEDS and SAROAD. A number of major changes and expansions in NEDS and SAROAD are currently underway, and it is essential that these receive continued support. The fundamental concept of a joint federal/state/local pollution control system depends on consistent, accurate, up-to-date bases readily available to all.

b. EPA should provide a greatly expanded nonurban ambient TSP data base, either through their own monitoring efforts or by encouraging and utilizing such monitors run by the states. There is a need for a clear understanding of the variation in ambient levels as one moves from remote nonurban areas through more proximate areas into suburban areas, as well as a need for more detailed data on the differences in levels between various portions of the continent. Current networks need to be reviewed for appropriateness, completeness, and possible local influences as discussed below.

c. EPA should conduct a study, based on existing nonurban sites, concerning the effect of height and distance on measured levels at such sites. Because of the long history of many of these sites, dating back to the earliest years of the NASN, they have apparently never been studied carefully from a siting viewpoint, and in fact many are apparently placed very close to the ground. Since they must of necessity provide data to be extrapolated over scales of hundreds of miles, it should be well-determined to what extent they reflect air masses on that large scale, and to what extent very local impacts may be important. The evaluation of the current network should be conducted with the point of establishing consistently sited monitors (height and neighborhood) and any changes in the siting should be documented through concurrent sampling for a period of time.

d. EPA should provide improved, more specific, network design and monitor siting guidelines for TSP monitoring in urban areas. Although the study cities visited were all major cities with active control programs and were all meeting the minimum monitoring requirements, an unfortunate number of circumstances arose where the data from these networks was inadequate to meet relatively simple analysis needs. Emphases in the recommended effort should include the minimization of local effects at sites, the development of inter-urban site standardization, and the encouragement of increased monitoring frequency for problem diagnosis purposes. The number of sites required for an area should not be based on an arbitrary formula but should be determined by the need to understand the full complexities of the TSP problem.

2. Development of Improved Planning Tools

   a. EPA should promote increased use by state and local agencies of special studies as planning tools. These studies would be directed at providing analytical procedures and control development tailored to the particular TSP situation and topographical, meteorological, industrial, and social-economic characteristics of a region through coordination with other environmental and regional planning efforts.

   b. State and local agencies responsible for emission inventory maintenance should reevaluate previous years' emission inventories to make them compatible with those inventories currently being used. A basic understanding of how the emissions situation has changed in the past and the resulting impact on air quality provides the soundest basis for future planning.

   c. EPA should support the development of the microscale dispersion models that are required to adequately cope with the potential need to control vehicular traffic in urban settings as a TSP control measure. At the present, the quantitative consideration of such matters is limited to the type of empirical data analysis performed herein. While essential for many purposes, this type of treatment does not allow for the consideration of hypothetical alternatives, as is necessary for control strategy formulation.

   d. EPA should develop both the conceptual framework and the requisite computer software needed to utilize long-distance air mass trajectory modeling as an air quality management tool available to the states. As increasing refinement of control strategies is necessary, concern with background transport, regional-scale secondary particulates, and other large-scale considerations will become increasingly important.

   e. EPA should develop and promulgate at least informally guidelines for the use of particulate analysis by microscopy and other analytical methods. The need to identify sources of particulate matter will very likely result in an increase in this work, and a mechanism is needed to assemble and make available experience with the various approaches.

f. EPA should assess and provide information to states on hardware available for and design of special field studies.

OTHER ASPECTS — NAAQS REVIEW

The nature of the control measures mentioned above with respect especially to many of the "nontraditional" sources of particulates and large-scale problems will significantly modify the nature of many pollution control programs. Implementation of some of the control measures will necessarily extend the scope of control programs into areas of municipal services that have not traditionally been involved in pollution control, and which will necessarily be costly. Consequently, they will no doubt require extended discussion and justification, not only in the eyes of public opinion, elected officials, and municipal executives, but also in the eyes of many personnel within the air pollution control community itself.

An important element in future planning concerns the actual standards themselves. The NAAQS are currently being reviewed by the National Academy of Sciences for appropriateness and completeness. While the purpose of this TSP attainment study did not involve addressing the need for standards review or the ongoing review by the NAS, five specific issues became apparent in the course of this study. These are listed below with the hope that they will be considered in the review of the standards for TSP.

1. Particle Size - At present, the particulate standard is based on the total mass of particulate matter suspended in the air; there is no concern with particle size, save that the particles be small enough to remain suspended. (Or actually, just to remain suspended long enough to reach the hi-vol, the proximity of which thus becomes crucial.) Because the health effects of particles of various sizes differ significantly, and because the size distribution of particles from various source types differs significantly, any standard, whether an emission standard or especially an ambient air standard, that fails to recognize such differences is unavoidably seen as oversimplified.

2. Particle Toxicity - Differential toxicity among particles of various chemical nature is an issue very like that of particle size. Known, obvious differences, such as the distinction between inorganic soil materials and organic coal tar derivatives,

are not included in the basis for the present ambient standard, except implicitly through the selection of epidemiological evidence to support the standard. This unavoidably contributes to the general impression that the standard is oversimplified in letting important factors "average out." The composition of the total particulates is already coming under review due to recent concerns about toxic pollutants.

3. Monitoring Specifications - At present, neither the NAAQS themselves nor the specified Federal Reference Method address the question of how hi-vol monitors should be placed relative to the sources of the particulate matter. While "common sense" has probably been adequate in distinguishing between ambient and source-oriented situations in the case of major point sources, it is clearly not so in the case of such low-level dispersed sources as street dust reentrainment. In order to be seen as appropriately precise in this area, the standards should at least take note of the effects of height and distance from a source such as a street by specifying a reference point for monitoring and defining relationships by which data from other points could be adjusted.

4. Time Scale of Standards - At present, the necessary recognition of differing averaging times is handled by having standards for both short-term and long-term (annual) averages, and this is generally considered adequate. However, there are some phenomena that operate on a longer-time period and tend to indicate a desirability in considering longer-term values as well, such as perhaps 5-year running averages. Such an approach would offer one way of resolving the difficulties in handling such features as meteorologically good and bad years in air quality planning. It would also help in rationalizing the situation caused by several-year temporary phenomena, such as major construction, which presently are viewed as anomalies, causing standards' violations that can be ignored because they are temporary.

5. Spatial Averaging - Similar to the problem of monitoring specifications is the concern over the Clean Air Act requirement that each and every area of a city meet the air quality standards. It can generally be assumed that every city has at least one corner which can not meet the standards even though the current monitoring network indicates no violations. In the same manner, monitors may be placed so as to ignore the problem. Average TSP levels within a certain area up to a set height may be more appropriate.

APPENDIX A

COMPARATIVE DATA ON THE 14 STUDY CITIES

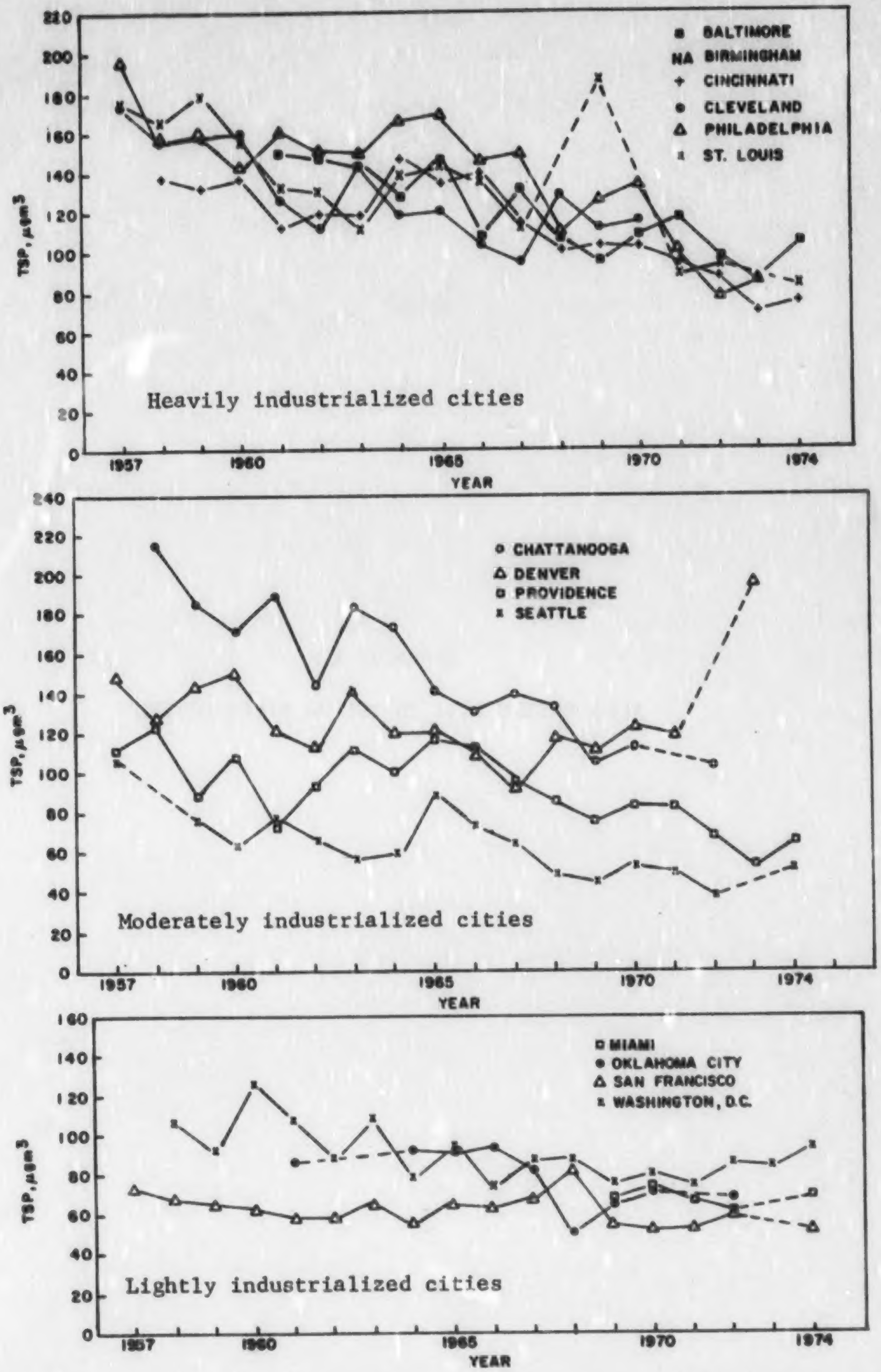

Figure A-1. Annual geometric mean TSP trends at NASN sites

Table A-1. RANKINGS OF 14 CITIES BY METEOROLOGICAL/CLIMATOLOGICAL PARAMETERS[a]

Annual precipitation (in.)		No. of days with precip ≥ 0.01 in.		Heating degree days (base 65°F)		Surface wind speed (mph)		Low-level inversion frequency[b] (% total hours)		No. of episode days in 5-year period[c] (Mixing ht. ≤ 1000 m; wind speed ≤ 4.0 m/sec)	
Denver	15.5	San Fran.	62	Clev.	6154	Chat.	6.3	Chat.	40	San Fran.	d
San Fran.	19.5	Okla.	82	Denver	6016	Birm.	7.4	Denver	39	Seattle	44
Okla.	31.4	Denver	88	Prov.	5972	Denver	9.0	San Fran.	38	Denver	27
Clev.	35.0	St. Louis	109	Seattle	5185	Cin.	9.1	Birm.	37	Birm.	22
St. Louis	35.9	Wash.D.C.	111	Cin.	5070	Miami	9.1	St. Louis	36	Chat.	20
Seattle	38.8	Balt.	112	Phil.	4865	Wash.D.C.	9.3	Okla.	35	Wash.D.C.	20
Wash.D.C.	38.9	Phil.	116	St. Louis	4750	Seattle	9.3	Cin.	31	Balt.	18
Cin.	39.0	Birm.	118	Balt.	4729	St. Louis	9.5	Seattle	30	Phil.	13
Phil.	39.9	Chat.	121	Wash.D.C.	4211	Balt.	9.5	Clev.	25	St. Louis	12
Balt.	40.5	Prov.	124	Okla.	3695	Phil.	9.6	Wash.D.C.	24	Clev.	11
Prov.	42.8	Cin.	129	Chat.	3505	San Fran.	10.5	Balt.	24	Cin.	10
Chat.	51.9	Miami	129	San Fran.	3044	Prov.	10.8	Phil.	23	Prov.	2
Birm.	53.2	Clev.	156	Birm.	2844	Clev.	10.8	Prov.	22	Miami	0
Miami	59.8	Seattle	161	Miami	206	Okla.	12.9	Miami	10	Okla.	0

[a] Except for episode days, data are mean annual values.

[b] Obtained from Hosler, C. R., Low-Level Inversion Frequency in the Contiguous United States. Monthly Weather Review, Vol. 89, September 1961, Fig. 1.

[c] Obtained from Holzworth, G. C., Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States, EPA, Office of Air Programs Publication No. AP-101.

[d] Index not quantitatively applicable to San Francisco.

Table A-1 (continued). RANKINGS OF 14 CITIES BY METEOROLOGICAL/CLIMATOLOGICAL PARAMETERS[a]

Mean wind speed through surface layer[c] (m/sec)				Mean mixing height[c] (m)				Median $\overline{X}/Q$ for 10-km city[c] (sec/m)			
AM		PM		AM		PM		AM		PM	
San Fran.	3.0	Seattle	5.4	Denver	268	San Fran.	1000	Denver	17	Denver	10
Denver	4.2	San Fran.	5.5	Okla.	377	Prov.	1050	Chat.	12.5	Birm.	10
Chat.	4.5	Birm.	5.5	Birm.	380	Seattle	1175	St. Louis	12	Chat.	10
Birm	4.6	Chat.	5.5	St. Louis	390	Clev.	1250	San Fran.	12	Seattle	10
Wash. D.C.	4.9	Denver	6.3	Chat.	440	Phil.	1350	Birm.	12	San Fran.	10
Balt.	5.1	Miami	6.5	Cin.	480	St. Louis	1350	Wash. D.C.	12	Miami	10
Seattle	5.2	Cin.	6.7	San Fran.	500	Miami	1351	Cin.	11	St. Louis	9
Clev.	5.2	Wash. D.C.	6.8	Wash. D.C.	528	Okla.	1382	Clev.	11	Clev.	9
Miami	5.3	Balt.	7.0	Clev.	540	Cin.	1390	Phil.	10.5	Cin.	9
St. Louis	5.5	St. Louis	7.0	Balt.	620	Balt.	1450	Balt.	10.5	Okla.	9
Phil.	6.0	Clev.	7.4	Prov.	690	Birm.	1500	Okla.	10	Wash. D.C.	9
Cin.	6.0	Phil.	8.0	Seattle	705	Wash. D.C.	1570	Seattle	10	Phil.	9
Prov.	7.2	Prov.	8.2	Phil.	750	Chat.	1600	Miami	10	Balt.	9
Okla.	7.8	Okla.	8.4	Miami	923	Denver	2543	Prov.	9	Prov.	9

[a] Except for episode days, data are mean annual values.

[c] Obtained from Holzworth, G. C., Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States, EPA, Office of Air Programs Publication No. AP-101.

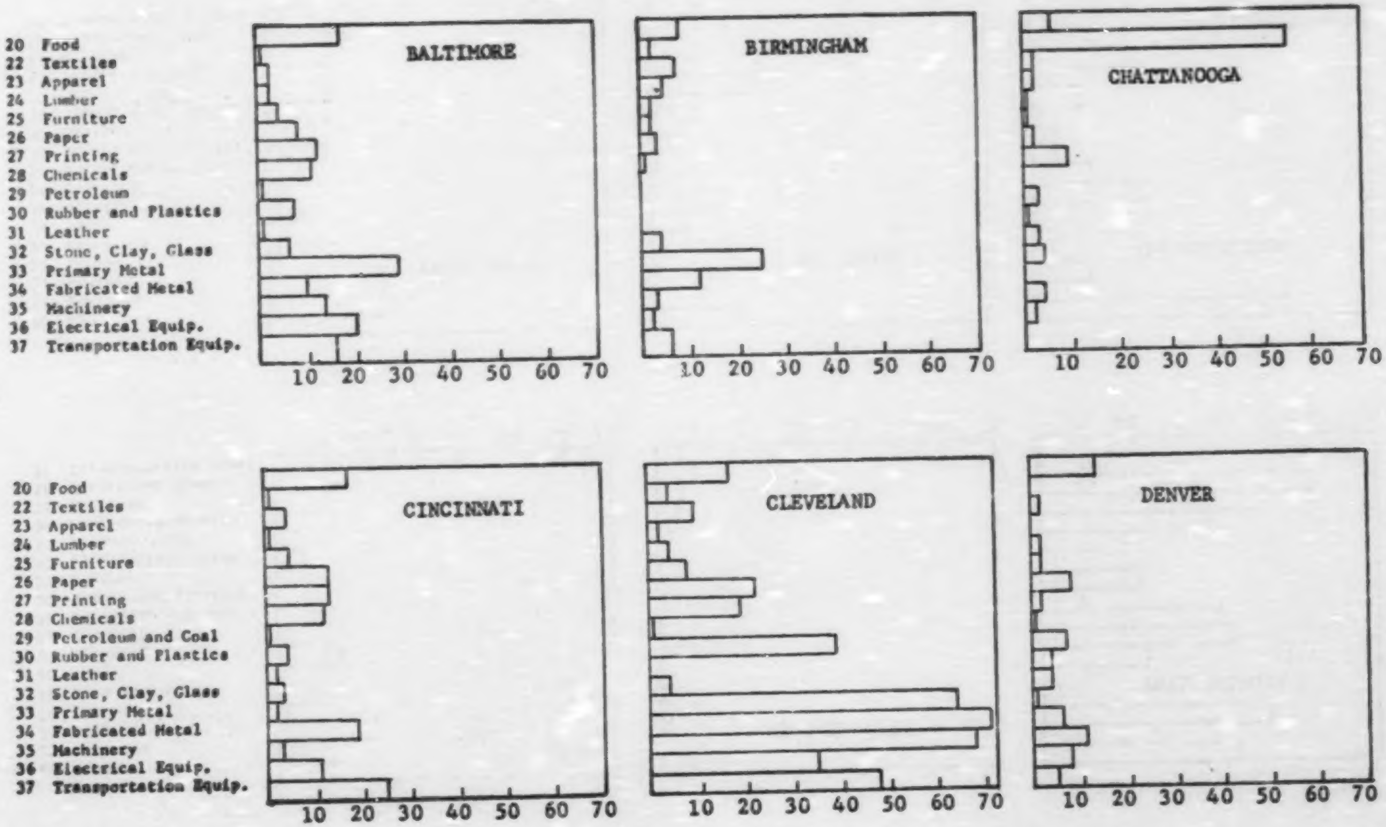

Figure A-2. AQCR manufacturing employment (thousands of employees)

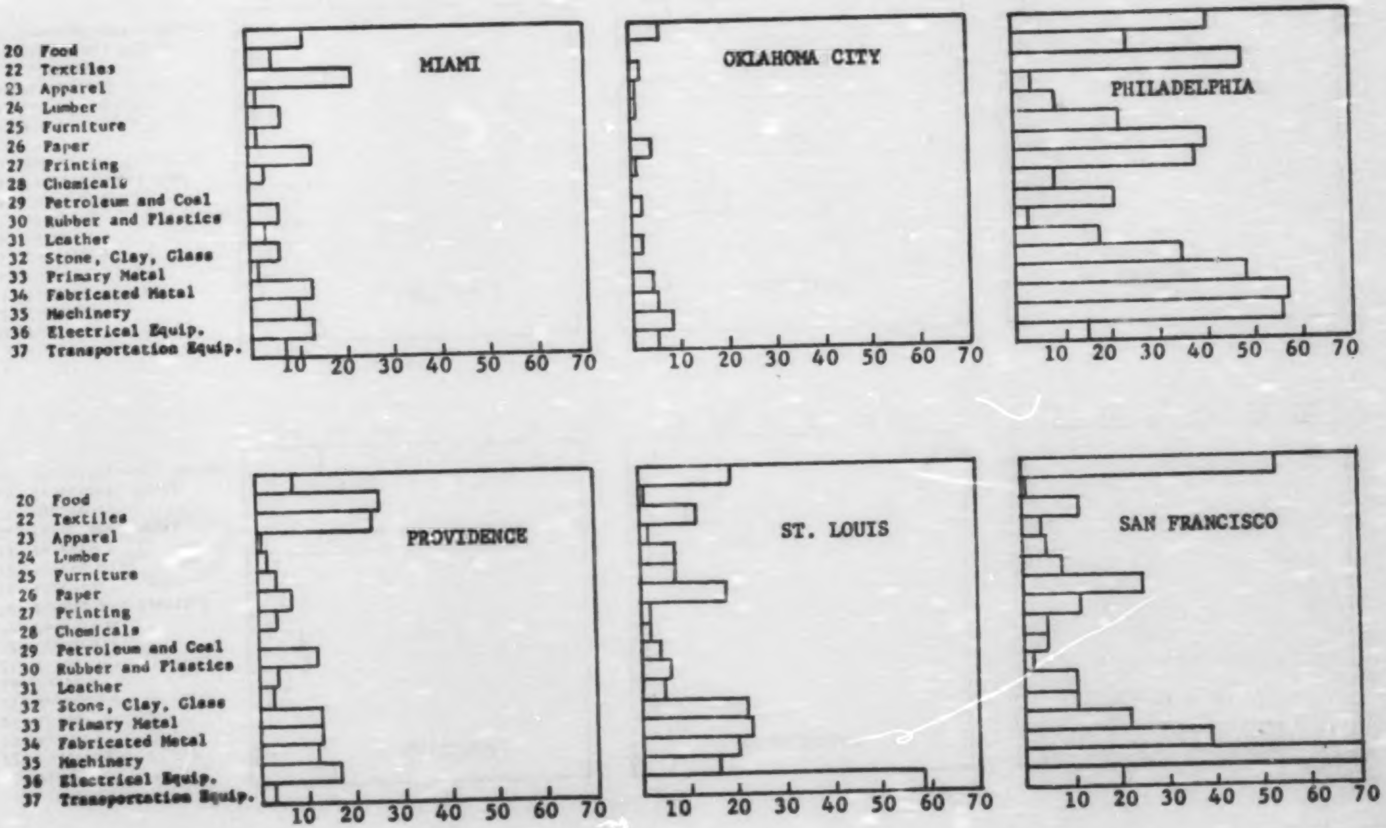

Figure A-2 (continued). AQCR manufacturing employment (thousands of employees)

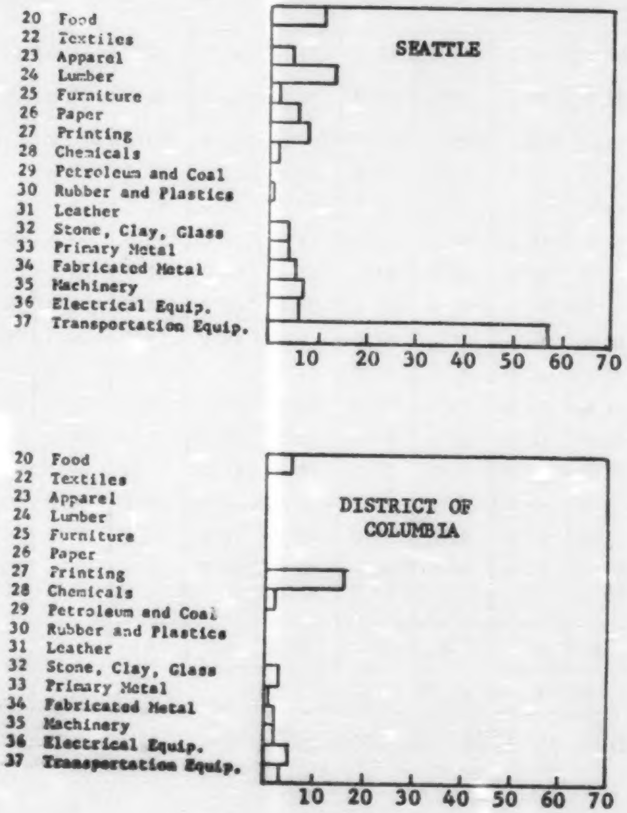

Figure A-2 (continued). AQCR manufacturing employment (thousands of employees)

Table A-2. REGULATIONS APPLICABLE TO FUEL-BURNING SOURCES' RATE OF EMISSIONS, lb particulate/10^6 Btu[a]

	Fuel input, 10^6 Btu/hr														
	0.01	1.0	4.0	10	20	40	70	100	200	400	700	1,000	3,000	10,000	100,000
Baltimore, residual oil	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Baltimore, solid fuel	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05
Birmingham	0.50	0.50	0.50	0.50	0.37	0.27	0.21	0.18	0.13	0.12	0.12	0.12	0.12	0.12	0.12
Chattanooga[b]	0.60	0.60	0.60	0.60	0.50	0.42	0.36	0.33	0.28	0.23	0.21	0.18	0.14	0.10	0.10
Cincinnati	0.40	0.40	0.40	0.40	0.33	0.27	0.22	0.20	0.17	0.13	0.11	0.10	0.10	0.10	0.10
Cleveland[c]	0.60	0.60	0.60	0.60	0.52	0.45	0.42	0.39	0.33	0.29	0.26	0.24	0.19	0.15	0.15
Denver	0.50	0.50	0.35	0.275	0.23	0.19	0.16	0.15	0.13	0.11	0.10	0.10	0.10	0.10	0.10
Miami	-	-	-	-	-	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Oklahoma City	0.60	0.60	0.60	0.60	0.55	0.42	0.39	0.35	0.29	0.25	0.22	0.20	0.14	0.10	0.10
Philadelphia[b]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Providence	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10	0.10	0.10
St. Louis	0.60	0.60	0.60	0.60	0.53	0.47	0.42	0.40	0.35	0.32	0.29	0.26	0.22	0.18	0.18
San Francisco	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Seattle[b]	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Washington, D.C.	0.13	0.13	0.126	0.102	0.086	0.073	0.064	0.059	0.050	0.043	0.037	0.034	0.027	0.02	0.02
Arithmetic mean	0.35	0.35	0.34	0.33	0.29	0.24	0.22	0.21	0.18	0.16	0.15	0.14	0.13	0.12	0.12
Standard deviation	0.21	0.21	0.21	0.21	0.18	0.14	0.13	0.12	0.10	0.09	0.08	0.78	0.07	0.06	0.06

[a] Appropriate conversions were made where allowable emissions were not directly expressed as lb/10^6 Btu.

[b] Regulation for existing sources.

[c] Ohio's regulation is the same as Cincinnati and was applicable to Cleveland sources as of July 1, 1975.

Table A-3. REGULATIONS APPLICABLE TO GENERAL PROCESS SOURCES' RATE OF EMISSIONS IN 14 STUDY CITIES, lb particulate/hr[a]

City	Process weight rate, lb/hr											
	100	400	1,000	4,000	10,000	40,000	100,000	200,000	400,000	700,000	1×10^6	4×10^6
Baltimore	0.46	1.50	2.80	5.93	10.0	28.30	44.58	51.28	58.51	64.76	68.96	86.90
Birmingham	0.56	1.32	2.34	5.52	9.76	23.0	32.37	36.17	40.41	44.19	46.79	58.41
Chattanooga	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.0	66.0	69.0	90.0
Cincinnati	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
Cleveland	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
Denver	0.56	1.32	2.34	5.52	9.74	23.0	32.37	36.17	40.41	44.19	46.79	58.41
Miami	0.56	1.32	2.34	5.52	9.74	23.0	32.37	36.17	40.41	44.19	46.79	58.41
Oklahoma City	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
Philadelphia	0.46	1.50	2.80	5.93	10.0	28.3	40.0	40.0	40.0	40.0	40.0	40.0
Providence	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
St. Louis	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
San Francisco	0.551	1.40	2.58	6.52	12.0	30.5	44.6	51.2	58.51	64.76	69.0	86.9
Seattle	0.60	1.50	2.80	6.50	12.0	30.5	55.0	75.50	92.0	104.75	114.0	138.0
Washington, D.C.	0.24	1.50	2.80	5.93	10.0	28.3	40.0	40.0	40.0	40.0	40.0	40.0
Arithmetic mean	0.52	1.41	2.59	6.18	11.09	28.42	42.06	48.12	54.34	59.76	63.31	77.97
Standard deviation	0.09	0.07	0.17	0.43	1.09	3.07	6.26	10.33	14.0	16.98	19.08	25.33

[a] Numbers are approximate due to rounding and conversion of units.

Table A-4. REGULATIONS APPLICABLE TO INCINERATORS' RATE OF EMISSIONS IN 14 STUDY CITIES,[a,b] lbs/100 POUNDS OF REFUSE CHARGED

Cities	Tons/day capacity		
	1.0	2.5	≥ 50
Baltimore	0.0285[c]	0.0285[c]	0.0285
Birmingham	0.20	0.20	0.10
Chattanooga	0.40	0.40	0.40
Cincinnati	0.20	0.10	0.10
Cleveland	0.20	0.10	0.10
Denver	0.1425	0.1425	0.1425
Miami	0.095	0.095	0.095
Oklahoma City	0.285	0.19	0.19
Philadelphia	0.095[c]	0.095[c]	0.095
Providence	0.076	0.076	0.076
St. Louis	0.285	0.19	0.19
San Francisco	0.1425	0.1425	0.1425
Seattle	0.095	0.095	0.095
Washington, D.C.	0.076	0.076	0.076
Mean	0.145	0.145	0.139

[a] Where both state and local regulations were applicable, the more stringent control is assumed.

[b] Numbers are approximate due to rounding and conversion of units.

[c] New incinerators in this size range are prohibited.

Table A-5. TYPES OF FUGITIVE PARTICULATE REGULATIONS IN STUDY CITIES

Cities	Recognition		Property line			Specific requirements
	Nuisance	Reasonable precaution	Prohibition	Opacity	Concentration	Type of source or control
Baltimore	X	X	X			
Birmingham		X	X			Operating procedures, control equipment, and maintenance requirements for coke ovens; sealing of buildings and treatment of exhaust
Chattanooga	X	X		X		
Cincinnati	X	X	X			Building emissions if a nuisance, building cleaning and repair, spray application of fiberated cementitious products
Cleveland	X	a		X	X	Building emissions if a nuisance[a]
Denver	X		a	a		Fugitive dust from unpaved roads, construction/demolition, mining, land development is regulated; permits are required[a]
Miami		X				
Oklahoma City		a				Hot mix axphalt plant; operating practices for material handling
Philadelphia		X	a		a	
Providence	X	X				
St. Louis		X				Building emissions
San Francisco	X					
Seattle		X				
Washington, D.C.		X				

[a] State regulation; all other designations refer to local agency regulations

APPENDIX B

MICROSCOPIC FILTER ANALYSIS

In all of the case study cities except Miami, where only NASN filters were available, members of the GCA study team acquired hi-vol filters from the 1974 filter banks of the cognizant state and/or local agencies. In addition, several filter samples for 1974 and selected earlier years were obtained from the federal filter bank. The filters were selected to be as representative as possible of specific site and neighborhood types - industrial, commercial, residential - and of periods of both high and moderate TSP levels. The results of the analyses were used in the process of analyzing the TSP problem in each city, within the bounds of the reliability of the results, and were also aggregated into composite results for each site, each city, and ultimately a national composite. The primary presentation of the analytical results is included in the separately-bound Volume II of the study report. The purpose of this Appendix is to provide within Volume I a more detailed summary of the results than is appropriate in the main text; in particular, the results of the quality control replications are included to provide some perspective on the reliability of the results.

SUMMARY OF RESULTS

Occasional large differences in replicate results warn against relying very heavily on the results of the analysis of any one filter. However, a random match-up between analyst and filter sample minimizes any systematic bias in composited results, particularly with large numbers of filters included. For summary purposes, only such composited results are presented hear although they should not be construed to be more than semi-quantitative in nature. Table B-1 presents citywide summaries, and Table B-2 presents a composite of the results from all 14 cities. The results are given in percent by weight of the visible material seen by the microscopist.

It is apparent that in nearly all of the study cities the predominant component is mineral material. In Oklahoma City and Denver, two areas with dry climate and acknowledged fugitive dust problems, minerals comprised more than 80 percent of the observed particulate. Even in areas of high industrial fuel usage and substantial heating requirements, the mineral components predominate. The products of combustion, though significant, generally comprised only about one-quarter of the observed particulate. In only two cities, Cincinnati and Cleveland, did the contribution of combustion products exceed 40 percent. Biological material generally was not a major contributor to the observed particulate matter, except in Chattanooga where over 15 percent was pollen and plant tissue. The average amount of rubber identified was highly variable from city to city. San Francisco particulate was reported to average 16 percent rubber, while two cities, Philadelphia and Washington, D.C. were reported to average only 2 percent rubber.

In Table B-2 all filters reported for the individual cities in Table B-1 have been combined. As stated previously, the predominance of minerals (65 percent) is apparent. Of these minerals, two components - quartz and calcite - account for 50 percent of the observed mass. The 25 percent of the mass attributed to combustion products is comprised of about equal quantities of oil soot, coal soot, miscellaneous soot, and glassy fly ash. This 14-city composite also shows a 3 percent contribution from biological materials and a 7 percent contribution from rubber.

In Table B-3 results from all the filters except the NASN filters have been composited by site classification. These results show the highest percent component at the various site types to be: minerals at underdeveloped (nonurban) sites, combustion products at industrial sites, biological materials at residential sites, and miscellaneous (principally rubber) at the commercial (CBD) sites. The average percentages in Table B-3 were applied to the average TSP concentration to provide the rough estimates of mass contribution by component that were presented in Table II-6 of Section II.

QUALITY CONTROL RESULTS

The hi-vol filters obtained during the study visits were first returned to a clean room at GCA/Technology Division offices for a visual inspection for artifacts or any evidence of sampler or filter malfunctions. The filters selected for analysis were assigned a randomly-generated five-digit number, which then subsequently served as the only identifier for the filter. Hence the microscopist examining the particles from the filter had no information concerning the city, site, TSP loading, or possible local sources associated with the sample. In addition, filters from at least two different cities were included in each batch provided to the analysts, so that any potential carry-over bias among filters in any one batch would be discouraged. The fact that the analysts nevertheless found results that were consistent in terms of similarities and differences among days, sites, and cities indicates that advance knowledge of the circumstances of the sample is not necessary for successful particle identification.

On the other hand, some significant concern about the quantitative estimation of various particulate components was caused by the results of replicate analyses on some of the filters. Two different laboratories participated in the microscopic analyses, with Walter C. McCrone Associates being responsible for the analysis of 400 filter samples and Eastern Analytical Laboratories, Inc. being responsible for the analysis of 45 filter samples. The use of randomly generated identifying numbers not only made the basic analyses as objective as possible, but also permitted submission of a large number of replicate samples without the advance knowledge of the microscopists. Since both laboratories utilized more than one analyst, these arrangements resulted in as many as four microscopists observing samples from the same filter and, in some cases, the same analyst examining replicate samples from the same filter as many as 3 times.

Table B-4 summarizes the differences between results reported by different analysts and by the same analyst when examining samples from the same filter. The two sections of the table, above and below the diagonal, provide the results for minerals and combustion products, the two classes of particles which together typically account for about 90 percent of the filter loadings. Table B-4 shows some very large average differences in the results reported, both by different analysts and by the same analyst. It appears, however, that the results of replicate analyses by a single analyst are more consistent that comparisons between analysts. Analysts A, B, and C were from one laboratory and analysts D and E from the other laboratory. Analyst D, who consistently differed substantially from the other analysts, was used very little during the program.

Volume II contains a more detailed presentation of the quality control data. The balance of this appendix summarizes the data by analyst and presents the statistical analysis of the replicate results. Table B-5 summarizes the interanalyst comparisons for two categories, minerals and combustion products. It is apparent from the means that some very sizable differences occur in the general run of two analysts' results. To provide some quantitative perspective, a simple t-test was made on the matched data from each pair of analysts. (The calculated Student's t-value presented in Table B-5 was calculated in such a way as to take account of the matched-pair nature of the data, so that the variability of the various filters does not inflate the t-value.)

Table B-6 presents the significance probabilities associated with the t-tests, and the verbal description of the meaning that we would attach to each probability. Although the assumptions underlying the t-test are not strictly met by these data, the results of the comparisons are sufficiently clear-cut that we have no important concern on that matter. Only three of the eight pairs for minerals (AB, CD, CE) and two for combustion products (AB, CD) exhibit sufficient consistency such that one can reasonably attribute the difference to chance. Additionally, two of the five pairs that do show agreement had only two comparisons so the ability to illustrate disagreement is limited.

Table B-7 summarizes the intra-analyst comparisons for the three microscopists that examined replicate samples from the same filter. In general the results were more consistent than were the comparisons between two analysts, but there were some distressingly large differences.

Given the inconsistencies documented above, it was decided to look at the more detailed components of the microscopy results for one pair of analysts to see whether any ready explanation could be found for some of the inconsistency. Table B-8 presents the results of this detailed analysis, involving analysts B and C. Though this one case can by no means be presented as being conclusive, it does bring up certain curiosities. Looking at the data in Table B-8, it is indicated that analyst B had, on the average, higher mineral readings than analyst C. Analyst C had higher readings for combustion products, and to a lesser extent biologicals, than did analyst B. The major contribution to these differences were calcite and quartz for minerals and incinerator fly ash for combustion products.

Table B-1. CITY-WIDE COMPOSITE SUMMARY OF FILTER ANALYSES IN 14 STUDY CITIES

City	Baltimore[b]		Birmingham[b]		Chattanooga		Cincinnati		Cleveland		Denver		Miami[c]	
No. of filters	27		22		21		20		21		20		3	
	Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent	
Components	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Minerals	(69)	52-88	(66)	14-90	(36)	3-96	(51)	24-88	(51)	28-85	(81)	62-97	(79)	75-83
Quartz	31	10-50	25	8-67	10	<1-30	19	5-63	18	5-35	55	37-84	9	7-10
Calcite	18	2-41	24	3-52	16	2-93	22	5-50	17	6-40	11	1-35	62	60-65
Feldspars	3	0-6	<1	0-4	8	0-20	3	0-10	4	0-10	7	0-15	4	4
Hematite	15	2-46	17	3-65	2	0-12	6	<1-45	12	2-50	5	1-18	4	4
Mica	<1		<1	0-2			<1		<1		3	0-6		
Other[a]	2	0-46	<1	0-3	<1	0-3	<1		<1		<1			
Combustion Products	(25)	11-61	(22)	2-86	(35)	8-78	(44)	9-84	(40)	10-70	(7)	1-19	(9)	7-12
Soot:														
Oil	9	0-60	4	0-86	7	0-40	9	0-52	9	0-30			4	4
Coal	5	0-52	2	0-10	14	0-40	6	0-20	12	0-25	1	0-20	3	2-4
Misc. soot[a]	4	0-50	12	0-71			<1		<1		4	0-14		
Glassy fly ash	6	0-42	3	0-20	5	0-76	24	1-66	15	4-55	1	0-5	2	1-4
Incinerator fly ash	<1		<1		9	0-26	4	0-30	2	0-10			<1	
Burned wood	<1						<1							
Burned paper	<1		<1				<1						<1	
Magnetite							<1		2	0-15				
Carbon black											1	0-19		
Other[a]	1	0-12	1	0-15										
Biological Material	(3)	<1-11	(2)	0-8	(16)	0-90	(1)	<1-5	(1)	<1-5	(1)	0-7	(<1)	
Pollen	<1		<1		7	0-25	<1		1	0-5	<1	0-4	<1	
Spores	<1		<1		<1	0-2	<1		<1		<1		<1	
Paper	<1		<1		<1	0-2	<1		<1		<1		<1	
Starch	1	0-8	<1		1	0-5	<1	0-1	<1		<1		<1	
Misc. plant tissue	2	0-10	2	0-8	8	0-80	1	0-5	<1		1	0-7	<1	
Leaf trichomes														
Miscellaneous	(3)	0-26	(10)	0-50	(13)	0-45	(4)	<1-20	(8)	tr-22	(11)	0-32	(12)	10-15
Iron or steel	1	0-10	2	0-25	<1	0-4	<1		2	0-20	<1		<1	
Rubber	2	0-26	8	0-50	13	0-45	4	0-20	6	0-20	11	0-32	12	10-15
Other[a]									<1					

Table B-1 (continued). CITY-WIDE COMPOSITE SUMMARY OF FILTER ANALYSES IN 14 STUDY CITIES

City	Oklahoma City		Philadelphia[b]		Providence		St. Louis		San Francisco		Seattle		Washington, D.C.	
No. of filters	27		26		25		26		14		23		25	
	Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent	
Components	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Minerals	(88)	63-99	(64)	6-93	(66)	28-92	(75)	21-99	(52)	29-73	(60)	30-96	(70)	39-87
Quartz	29	10-65	29	2-60	39	11-71	26	4-50	25	15-50	35	7-65	31	15-60
Calcite	45	15-75	19	1-68	7	2-31	40	16-68	7	2-16	9	1-20	15	5-45
Feldspars	3	<1-4	2	0-5	7	0-20	2	0-20	18	6-35	10	0-28	3	2-4
Hematite	11	0-30	15	0-40	8	0-18	7	0-30	2	0-8	5	1-15	20	10-50
Mica	<1		<1		3	0-15			<1		<1		<1	
Other[a]							<1	0-5			1	0-4	<1	
Combustion Products	(8)	1-31	(33)	6-89	(22)	4-68	(21)	1-79	(29)	10-50	(27)	1-62	(23)	5-49
Soot:														
Oil	5	1-25	8	0-60	12	0-63	2	0-5	3	0-8	10	0-25	13	2-30
Coal	2	<1-4	2	0-15	2	0-15	<1	0-2	9	0-25	6	0-22	3	<1-5
Misc. soot[a]			18	0-88	4	0-27	16	0-79	<1	0-2	1	0-16		
Glassy fly ash	1	0-3	5	0-30	2	0-29	2	0-10	1	0-10	<1		7	<1-20
Incinerator fly ash	<1		<1		1	0-14	<1	0-2	15	0-45	9	0-45	<1	
Burned wood	<1		<1				<1		1	0-10	<1		<1	
Burned paper	<1		<1				<1				<1		<1	
Magnetite									<1	0-2	1	0-6		
Carbon black					1	0-10								
Other[a]														
Biological Material	(<1)	<1-4	(1)	0-10	(1)	0-5	(<1)	0-5	(3)	tr-10	(3)	tr-24	(5)	<1-47
Pollen	<1		<1		<1		<1		2	tr-5	1	0-20	4	<1-45
Spores	<1	<1-2	<1		<1		<1		<1		<1	0-2	<1	
Paper	<1		<1		<1	0-2	<1		<1		1	0-3	<1	
Starch	<1	0-1	1	0-10	<1		<1		<1		<1	0-2	<1	
Misc. plant tissue	<1	<1-2	<1		1	0-4	<1	0-5	1	0-5	<1	0-2	1	0-3
Leaf trichomes											1	0-18		
Miscellaneous	(4)	<1-30	(2)	0-30	(13)	0-35	(4)	0-10	(16)	0-35	(10)	<1-40	(2)	<1-25
Iron or steel	<1		<1		<1		<1				<1	0-2	<1	
Rubber	4	0-30	2	0-30	13	0-35	4	0-10	16	0-26	10	0-40	2	0-25
Other[a]									<1	0-10	<1	0-15	<1	0-10

[a] For specific composition of miscellaneous soot and other components, refer to the Composite Summary of Filter Analyses table for the individual city.

[b] Excludes Filter analyses of NASN site samples.

[c] Filter analysis of NASN site samples only.

Table B-2. U.S. COMPOSITE SUMMARY OF FILTER ANALYSES[a]

No. of filters	300	
	Quantity, percent	
Components	Average	Range
Minerals	(65)	3-99
Quartz	29	<1-84
Calcite	21	1-93
Feldspars	5	0-35
Hematite	10	0-65
Mica	<1	0-15
Other[b]	<1	0-46
Combustion Products	(25)	1-89
Soot:		
Oil	7	0-86
Coal	5	0-52
Misc. soot[b]	5	0-88
Glassy fly ash	6	0-30
Incinerator fly ash	2	0-45
Burned wood	<1	0-10
Burned paper	<1	0-<1
Magnetite	<1	0-15
Carbon black	<1	0-19
Other[b]	<1	0-15
Biological Material	(3)	0-90
Pollen	1	0-45
Spores	<1	0-2
Paper	<1	0-3
Starch	1	0-10
Misc. plant tissue	1	0-8
Leaf trichomer	<1	0-18
Miscellaneous	(7)	0-50
Iron or steel	<1	0-25
Rubber	7	0-50
Other[b]	<1	0-15

[a] U.S. summary based on the filter analysis of the 14 study cities, located within the 48 contiguous states

[b] For specific composition of misc. soot and other components, refer to the Composite Summary of Filter Analyses table for the individual cities

Table B-3. COMPOSITE SUMMARY OF FILTER ANALYSES BY SITE CLASSIFICATION[a]

Site classification	Commercial		Residential		Industrial		Undeveloped	
No. of filters	114		90		71		11	
No. of sites	29		21		19		5	
Average concentration, µg/m^3	120		92		166		86	
	Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent	
Components	Average	Range	Average	Range	Average	Range	Average	Range
Minerals	(63)	6-99	(65)	3-99	(62)	9-96	(90)	79-99
Quartz	28	2-80	31	<1-84	27	2-70	32	15-60
Calcite	20	1-75	18	2-70	20	0-93	40	10-60
Feldspars	6	0-35	4	0-20	4	0-45	3	<1-4
Hematite	9	0-45	12	0-65	10	1-50	15	5-50
Mica	<1	0-6	<1	0-15	<1	0-6	<1	
Other[b]	<1	0-5	<1	0-5	1	0-46		
Combustion Products	(26)	2-86	(25)	3-84	(30)	1-89	(8)	1-18
Soot:								
Oil	8	0-86	9	0-63	6	0-40	5	1-10
Coal	4	0-34	5	0-52	6	0-40	2	<1-4
Misc. soot[b]	7	0-84	3	0-77	7	0-88		
Glassy fly ash	4	0-55	6	0-66	7	0-76	1	<1-4
Incinerator fly ash	3	0-45	1	0-20	3	0-45	<1	
Burned wood	<1		<1	0-1	<1	2-10	<1	
Burned paper	<1		<1	0-1			<1	
Magnetite	<1		<1	0-8	1	0-15		
Carbon black			<1	0-19				
Other[b]			<1	0-15	<1	0-12		
Biological Material	(2)	0-47	(4)	<1-90	(2)	0-33	(1)	<1-4
Pollen	1	0-45	2	0-30	1	0-25	<1	
Spores	<1	0-2	<1	0-3	<1		<1	0-2
Paper	<1	0-2	<1	0-3	<1	0-2	<1	
Starch	<1	0-10	<1	0-5	<1	0-10	<1	
Misc. plant tissue	1	0-17	2	0-80	1	0-7	1	0-3
Leaf trichomer					<1	0-6		
Miscellaneous	(9)	0-50	(6)	0-28	(6)	0-45	(1)	<1-6
Iron or steel	<1	0-4	<1	0-2	1	0-25	<1	
Rubber	9	0-50	6	0-28	5	0-45	1	0-6
Other[b]	<1	0-10	<1	0-10	<1	0-15		

[a] Excludes all NASN filters

[b] For specific composition of misc. soot and other components, refer to the Composite Summary of Filter Analyses table for the individual cities

Table B-4. SUMMARY OF DISCREPANCIES IN DUPLICATE ANALYSES

Combustion products (below diagonal)

	Minerals (above diagonal)				
Analyst	A	B	C	D	E
A	56 18 (8) (8)	21 (14)	69 (10)	149 (6)	77 (15)
B	75 (14)	25 13 (7) (7)	71 (8)	–	79 (18)
C	66 (10)	94 (8)	– –	128 (2)	31 (13)
D	133 (6)	–	89 (2)	– –	172 (1)
E	92 (15)	124 (18)	50 (13)	111 (1)	48 49 (2) (2)

Note: Each entry is the average difference between the results reported for pairs of repeated analyses of the same filter, expressed as the percentage of the mean of the two reported results in each case. The entries along the main diagonal summarize the replicate analyses by the same analyst, while those off the diagonal are averages of the comparisons between two analysts. The number of paired analyses in each comparison is given in parentheses.

Table B-5. COMPARISONS OF MICROSCOPISTS: MINERALS AND COMBUSTION PRODUCTS

	A	B	A	C	A	D	A	E	B	C	B	E	C	D	C	E
Minerals																
Mean percentage by weight	69	78	56	31	70	6	62	37	75	36	77	35	30	5	38	39
Standard deviation	22	11	26	14	31	2	28	16	9	10	16	14	23	0	10	12
Differences between means	9		25		64		25		39		42		25		1	
Degrees of freedom	13		9		5		14		7		17		1		12	
t-value	1.6		2.9		5.1		3.0		12.4		11.5		1.6		0.1	
Combustion products																
Mean percentage by weight	22	16	29	43	27	86	31	61	16	40	15	59	38	95	38	59
Standard deviation	25	10	26	13	32	19	29	18	10	13	12	15	16	0	15	14
Difference between means	6		14		59		30		24		44		57		21	
Degrees of freedom	13		9		5		14		7		17		1		12	
t-value	1.1		2.3		2.9		3.5		6.3		11.3		5.0		4.0	

Table B-6. SIGNIFICANCE OF DIFFERENCES BETWEEN MEANS

Minerals

Analysts	Probability associated with t	Difference between means
A B	$0.10 < P < 0.20$	Not significant
A C	$P \approx 0.02$	Significant
A D	$0.001 < P < 0.005$	Significant
A E	$0.005 < P < 0.01$	Significant
B C	$P < 0.001$	Extremely significant
B E	$P < 0.001$	Extremely significant
C D	$0.30 < P < 0.40$	Not significant
C E	$P > 0.90$	Not significant

Combustion Products

Analysts	Probability associated with t	Difference between means
A B	$0.25 < P < 0.30$	Not significant
A C	$0.025 < P < 0.05$	Significant
A D	$0.025 < P < 0.05$	Significant
A E	$0.001 < P < 0.05$	Significant
B C	$P < 0.001$	Extremely significant
B E	$P < 0.001$	Extremely significant
C D	$0.10 < P < 0.20$	Not significant
C E	$0.001 < P < 0.005$	Significant

Table B-7. CONSISTENCY OF INDIVIDUAL MICROSCOPISTS

Analyst	Average percent difference between observations	Number of comparisons
Minerals		
Analyst A	18	8
Analyst B	13	7
Analyst E	49	2
Combustion products		
Analyst A	56	8
Analyst B	25	7
Analyst E	48	2
Biologicals		
Analyst A	85	8
Analyst B	81	7
Analyst E	34	2
Rubber		
Analyst A	118	8
Analyst B	117	7
Analyst E	0	2

Table B-8. CONSTITUENT ANALYSIS: B C[a]

Components	B	C	Difference (B − C)
Minerals	75	36	39
Quartz	29	16	13
Calcite	34	6	28
Feldspars	3	12	-9
Hematite	8	2	6
Mica	—	—	—
Coal	—	—	—
Combustion products	16	40	-24
Soot:			
Oil	13	6	7
Coal	1	7	-6
Fine soot	—	1	-1
Glassy fly ash	2	—	2
Incinerator fly ash	—	27	-27
Burned wood	—	—	—
Burned paper	—	—	—
Magnetite	—	—	—
Biologicals	2	10	-8

[a] All numbers represent percent contribution to the total TSP level and are mean values

APPENDIX C

A CASE STUDY OF LONG-RANGE TRANSPORT

INTRODUCTION

Long-range transport of particulates can be significant at particle sizes of less than about 10 μm in diameter. For such particles, the normal turbulent motions of the atmosphere may be sufficient to keep them suspended for considerable periods of time. Because of ever-changing atmospheric conditions, there is, of course, no sharp cut-off in particle size where the effects of gravitational forces are no longer of consequence. However, for very small particles of diameters of 1 μm or less, such as the secondary particulates formed by chemical reactions within the atmosphere, transport over distances of many miles is common before removal by deposition and washout. Such long-range transport from very large sources of pollution, such as major centers of industrial activity, large urban areas, and power plant complexes, can be significant since dispersion in these cases may well be inadequate to reduce concentrations to acceptable levels within reasonable travel distances.

This long-range transport of particulates has often been blamed for causing excessive levels of TSP. Specifically, the bulk transport of both primary and secondary fine particulates into the northeastern part of the United States is believed to be a significant contributor to the particulate problem of that area. Conditions favorable for transport into the region from outside sources occur during periods of sustained southerly or southwesterly flow resulting from either a stagnating or slowly moving anticyclone over the eastern United States or from the westward extension of the Bermuda High. Contributions are greatest when the transport flow is restricted to a relatively shallow layer by an upper level inversion.

The path of transported material is determined by the wind field over the depth of the atmosphere through which the material has been mixed. By making suitable assumptions, this path may be calculated in a step-by-step fashion from wind speed and direction data obtained from synoptic charts. Uncertainties are introduced by defining the appropriate air space over which the vectorial mean velocity is to be calculated, especially if the calculations extend over several days and include periods when large diurnal variations in mixing height take place. Nonetheless, the use of computer-calculated trajectories is proving most helpful in understanding the influence of long-range transport on air quality measurements. This appendix presents an example of such a trajectory analysis* for 3 sampling days at Oklahoma City, ending with a day of exceptionally high TSP and sulfate levels.

CASE STUDY FINDINGS

The period described extends from the evening of 23 June 1974 through 29 June 1974, the date on which the high particulate concentrations were observed. The surface weather observations show passage of a cold front at Oklahoma City late in the evening of the 22nd. This front continued southward, reaching the Gulf of Mexico by the morning of the 24th. On the 24th a large elongated high pressure area with NE-SW axis was centered over Lake Superior and covered the central United States. For the next few days this high pressure area drifted slowly eastward, with the surface ridge line remaining almost stationary during the 27th and 28th and extending from just west of Chicago to eastern Oklahoma. On the 29th, moderately strong southerly winds (averaging 16.5 miles per hour) returned to Oklahoma City. Figures C-1 through C-4 give the sequence of surface weather maps at 48-hour intervals for this period, and Table C-1 gives detailed precipitation and wind data from the Will Rogers International Airport in Oklahoma City.

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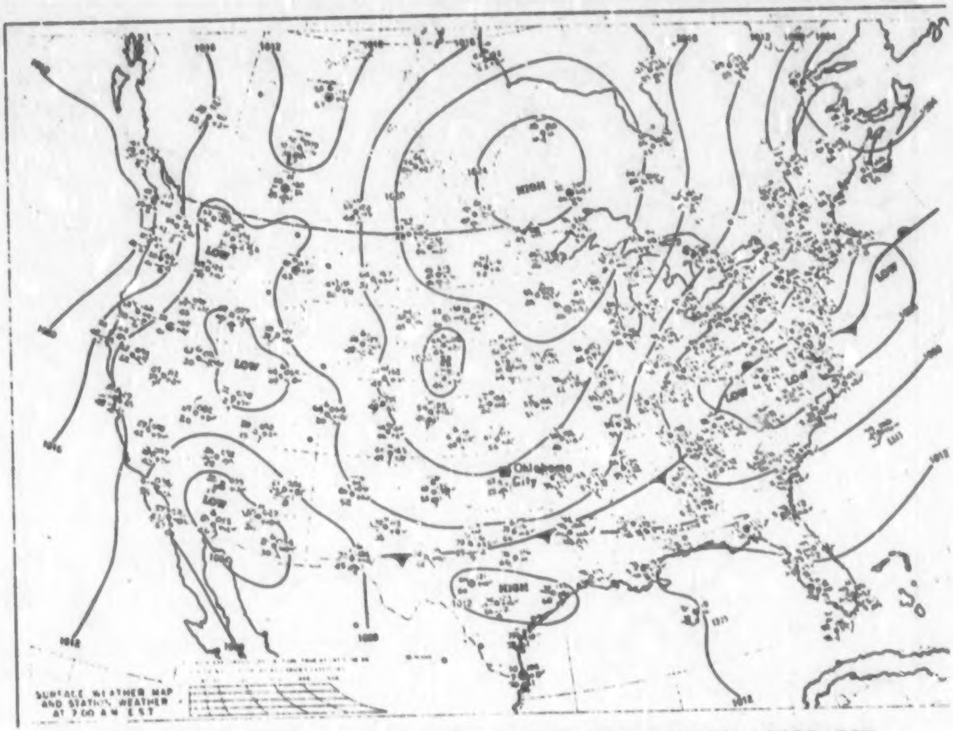
*The trajectories were calculated for a 300 to 1000 meter layer using the trajectory model developed by the Air Resources Laboratories, NOAA, and were provided by Dr. Lester Machta and Jerome Heffter of ARL.

TSP concentrations were measured at Oklahoma City on June 23rd, 26th and 29th. Figure C-5 shows the trajectories of air parcels arriving at Oklahoma City at noon the first 2 sampling days, and at the beginning and at noon of the last sampling day. The average concentrations observed at six sites on those days were, respectively, 68, 88, and 204 $\mu g/m^3$. Sulfate concentrations determined from seven hi-vol filters on the 29th averaged 13.8 $\mu g/m^3$, an unusually high value for that part of the country.

This analysis indicates that the meteorological event which led to the high concentrations at Oklahoma City on the 29th is not the southerly flow associated specifically with the immediate recent history of the air mass reaching the city. Rather, the high concentrations are the result of the sequence of weather patterns controlling the earlier history of the air mass during which it moved south-southwestward from Michigan, presumably accumulating particulates and sulfate precursors from the industrial activities along its path.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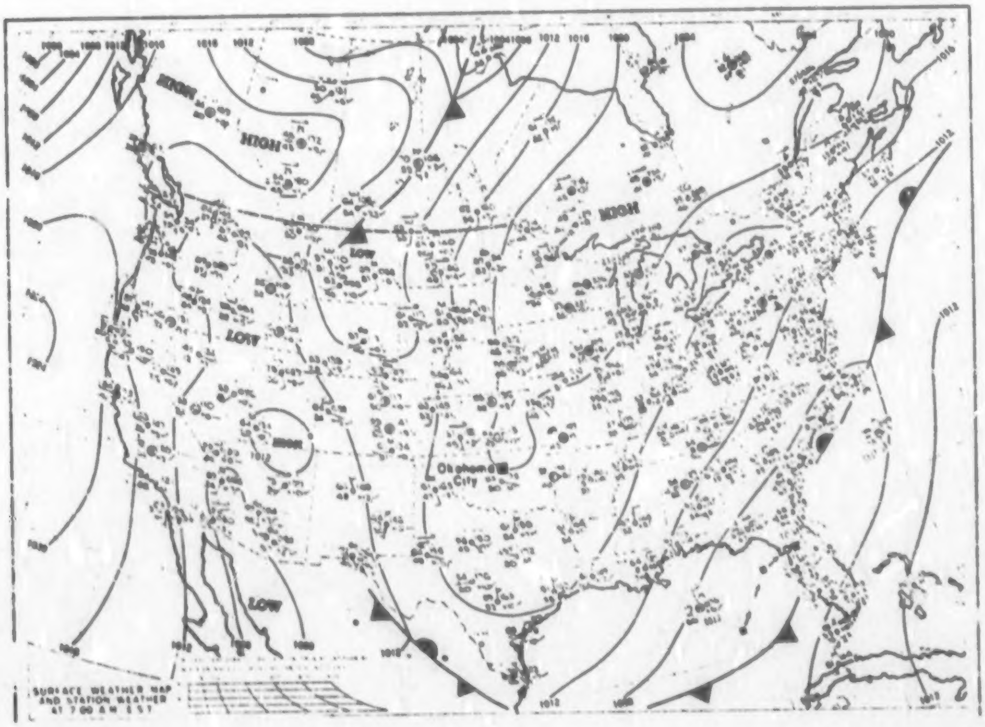
Oklahoma City
1012
1016
SURFACE WEATHER MAP AND STATION WEATHER AT 7:00 A.M. E.S.T.

Figure C-1. Surface weather map for 23 June 1974, 0600 CST


HIGH
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Oklahoma City
1012
1016
SURFACE WEATHER MAP AND STATION WEATHER AT 7:00 A.M. E.S.T.

Figure C-2. Surface weather map for 25 June 1974, 0600 CST

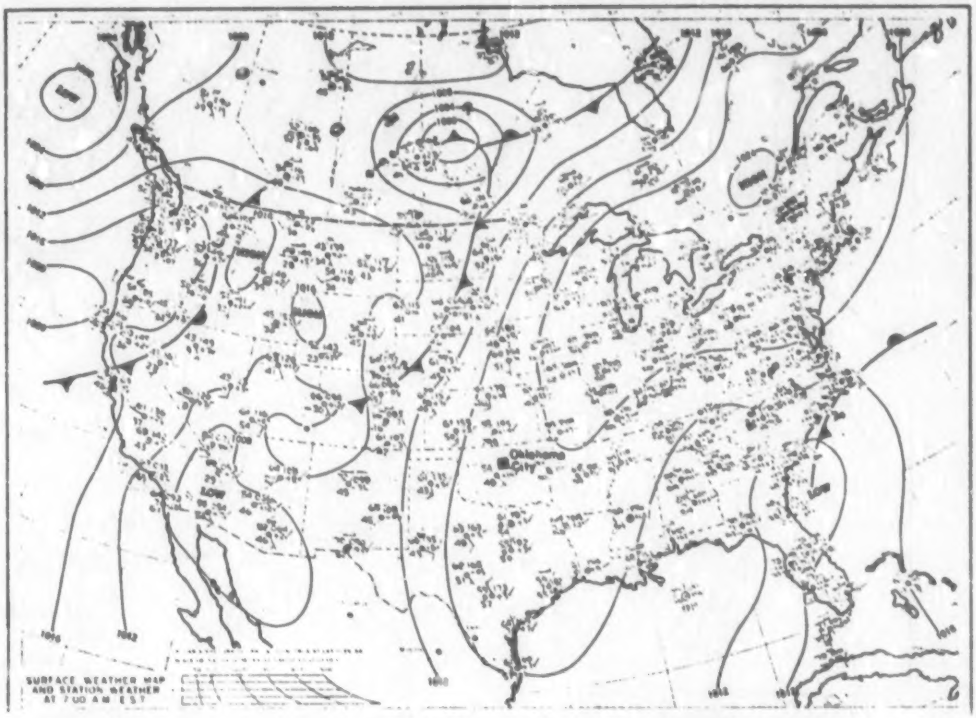

SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M. E.S.T.
Oklahoma City
LOW
LOW

Figure C-3. Surface weather map for 27 June 1974, 0600 CST

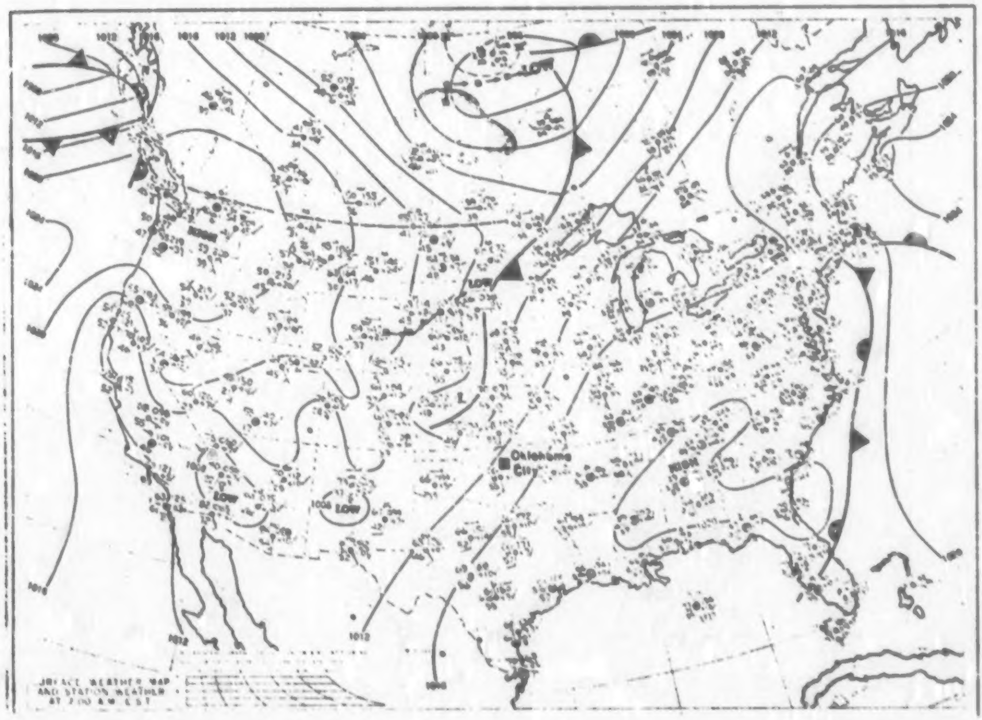
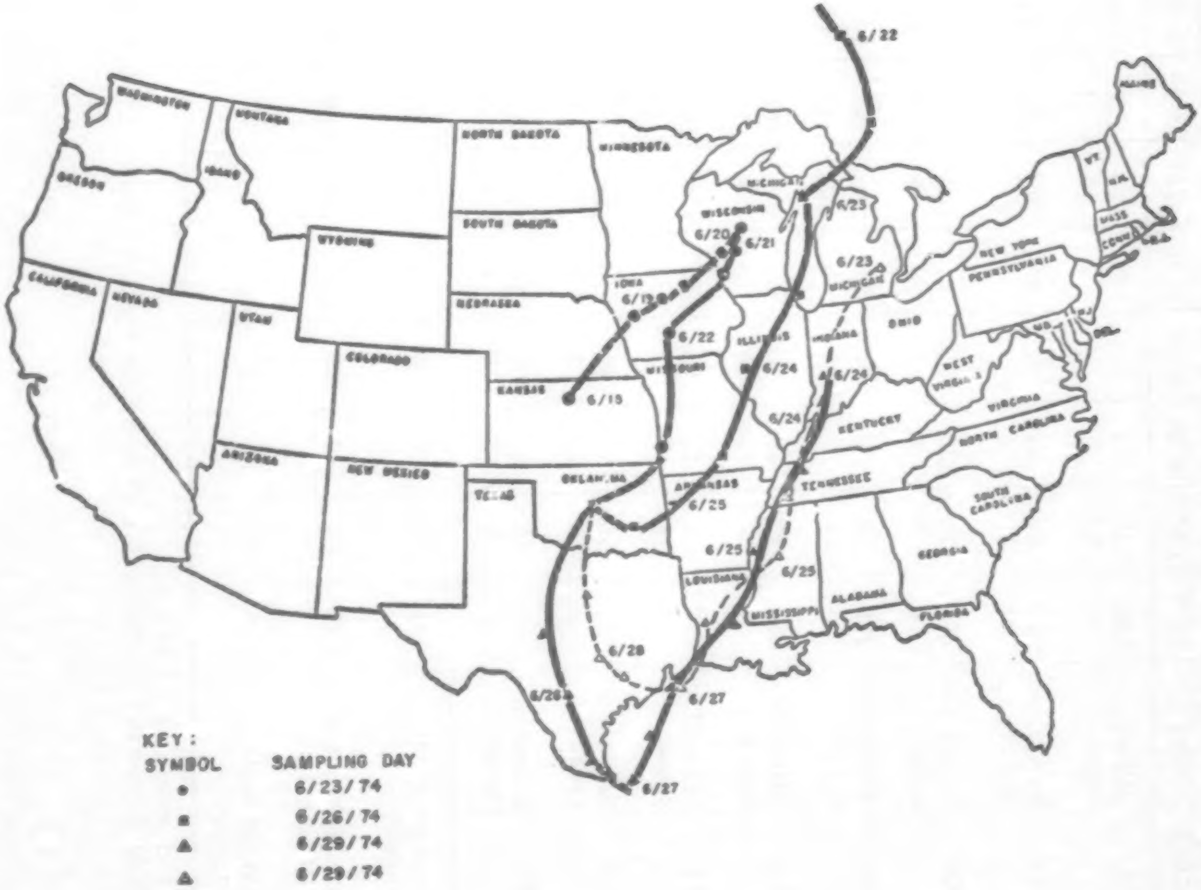

SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M. E.S.T.
Oklahoma City
LOW
LOW
LOW
LOW

Figure C-4. Surface weather map for 29 June 1974, 0600 CST

Table C-1. METEOROLOGICAL DATA FOR PERIOD 22 TO 29 JUNE 1974

Hour (CST)	Wind*	Day							
		6/22	6/23	6/24	6/25	6/26	6/27	6/28	6/29
00	Direction	160	30	40	70	80	110	120	150
	Speed	11	13	5	7	7	5	7	11
03	Direction	170	40	60	C	C	120	150	150
	Speed	11	12	6			5	8	11
06	Direction	200	50	330	120	C	140	160	170
	Speed	6	8	6	4		3	6	11
09	Direction	220	30	20	50	170	180	160	200
	Speed	14	11	7	9	5	10	15	15
12	Direction	240	30	40	50	60	140	200	200
	Speed	6	11	10	6	10	5	15	21
15	Direction	10	40	10	50	90	180	170	180
	Speed	9	16	7	7	7	10	10	21
18	Direction	20	30	40	80	110	170	160	150
	Speed	8	12	10	7	8	7	14	14
21	Direction	40	50	50	100	110	120	140	180
	Speed	7	5	8	5	6	6	9	11
Average wind speed		9	11	7	6	5	6	11	14
Resultant wind direction		190	40	30	70	100	150	160	180
Precipitation, inches		0.02	0	0	0	0	0	0	0

*Wind speed is in knots.
Wind direction is direction from which the wind blows in degrees.


6/22
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6/28
6/26
6/27
6/27
KEY:
SYMBOL SAMPLING DAY
● 6/23/74
■ 6/26/74
▲ 6/29/74
△ 6/29/74
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE
VT
N.H.
MASS
CONN
MD
NJ
DEL

Figure C-5. Trajectories of air parcels arriving at Oklahoma City at noon on three TSP sampling days (filled symbols), and at midnight at the start of one of the sampling day (open Triangle). Dates show positions at 24-hour intervals.

APPENDIX D

ASSESSMENT OF TRADITIONAL SOURCE IMPACT ON TSP STANDARDS ATTAINMENT

The most apparent of the many factors affecting attainment of the TSP standards are the particulate emissions from three obvious major categories of pollution sources — fuel combustion, industrial processes, and solid waste disposal operations. These three categories have long been recognized as significant pollution problems, and have traditionally been the primary concern of air pollution control efforts. In most of the case study areas, emissions from these traditional sources continue to be a major concern; in some of the cities they constitute a major share of the problem, either generally or only in some areas.

The aggregate traditional source emission estimates and air quality data for each of the 14 study cities are listed in Table D-1; these emission levels generally represent the central city or county in each area, with appropriate modifications made to ensure the comparability of the numbers, at least within the precision limitations typical of emission inventories. A comparison of the first two columns of Table D-1 indicates that particulate emissions from motor vehicles, the only other category routinely included in the inventories, is roughly comparable among the cities. A comparison of emissions with air quality levels in Table D-1 suggests that emissions from the traditional source categories — fuel combustion, industrial processes, and solid waste — are important factors in affecting standards attainment. Unfortunately, the degree to which traditional sources are a factor in nonattainment cannot be judged from the emission estimates, because emissions from other sources are typically not included.

Table D-1. COMPARISON OF EMISSIONS AND ANNUAL TSP LEVELS IN THE 14 STUDY CITIES

Cities	Inventoried emissions estimates, tons/year		1974 ambient TSP concentration,[a] $\mu g/m^3$	
	Traditional sources	Other[b]	Highest site	Citywide average
Heavily industrialized				
Cleveland	210,000	6,400	175	116
Birmingham	110,000	3,400	144	99
Philadelphia	31,600	6,700	122	87
Baltimore	23,700	5,700	134	95
St. Louis	190,000	4,200	158	88
Cincinnati	36,100	1,800	130	80
Average				94
Moderately industrialized				
Chattanooga	10,300	5,400[c]	101	71
Denver	9,700	3,000	131	109
Seattle	7,300	5,200	105	63
Providence	7,800	2,200	88	61
Average				76
Lightly industrialized				
Washington	5,600	1,500	102	67
Oklahoma City	2,600	3,900	107	66
Miami	8,000	4,900	86	59
San Francisco	4,800	6,600	74	52
Average				62

[a] See also Table 3.

[b] Generally transportation only.

[c] Includes 3,900 tons per year fugitive dust emissions.

This appendix addresses the interrelationships between traditional source emissions and the problem of attaining the TSP standards. Therefore, the following discussion considers not only the actual emissions and air quality data but also the stringency of controls being applied and the enforcement of these controls.

TRADITIONAL SOURCE EMISSIONS

The relative contributions of emissions from the three major traditional source categories are tabulated for each of the study cities in Table D-2. Comparative judgments concerning either percentage contributions or actual emission tonnages based on this table should not be interpreted too quantitatively, because the data are subject to possible differences in definitions among the cities as well as the normal difficulties with any emission inventories. Nonetheless, fuel combustion is of some importance in most of the cities except Birmingham, Miami, and San Francisco, all relatively warm and/or primarily gas-burning areas. Similarly, industrial processes are a significant proportion of traditional source emissions in most of the cities, including all the heavily industrialized cities. Solid waste disposal is currently a minor share of the traditional source total; it comprises a significant percentage only in those cities where some incineration is still practiced, including Baltimore and some of the relatively nonindustrialized areas.

Fuel Combustion Emissions

While the magnitude of fuel combustion emissions depends primarily on the fuels burned, the degree to which they are or can be controlled also depends on two further classifications: size and type of source. The different fuel combustion sources are typically identified in two size categories — point sources and area sources. The major categories of fuel combustion point sources are power plants and the industrial and other large installations that use the energy from fuel combustion on their premises for space heating or manufacturing products. Area source fuel combustion, on

Table D-2. CONTRIBUTIONS OF MAJOR TRADITIONAL SOURCE CATEGORIES IN THE 14 STUDY CITIES

Cities	Estimated emissions, tons per year				Relative contribution, percent		
	Fuel combustion	Industrial process losses	Solid waste disposal	Total	Fuel combustion	Industrial process losses	Solid waste disposal
Heavily industrialized							
Cleveland	126,000	77,600	6,900	210,500	60	37	3
Birmingham	15,700	91,300	2,700	109,700	14	83	3
Philadelphia	17,100	11,900	2,600	31,600	54	38	8
Baltimore	5,300	15,800	2,600	23,700	22	67	11
St. Louis	67,000	119,000	3,500	189,500	35	63	2
Cincinnati	54,000	1,400	700	56,100	96	3	1
Moderately industrialized							
Chattanooga	7,100	3,100	100	10,300	69	30	1
Denver	7,600	1,900	200	9,700	78	20	2
Seattle	3,200	3,800	300	7,300	44	52	4
Providence	4,700	600	2,500	7,800	60	7	33
Lightly industrialized							
Washington, D.C.	5,500	40	100	5,600	97	1	2
Oklahoma City	1,800	800	0	2,600	69	31	0
Miami	1,400	5,800	800	8,000	18	72	10
San Francisco	800	3,500	500	4,800	17	73	10

the other hand, involves almost totally residences and small commercial and apartment buildings, which burn fuel for space-heating in small furnaces and boilers.

In any city, the amount of particulate emissions from fuel combustion depends on the amount and type of fuel consumed, which is determined in turn by the degree of urban and industrial development, the types of industries, and the climate and location of the city. Table D-3 shows, for the 14 cities, the total energy use and the mix between fuels for the industrial and utility sectors, which could be expected to be primarily point source emissions. The total industrial energy consumption is highest in Philadelphia, San Francisco, St. Louis, and Cleveland, and lowest in Washington, Oklahoma City, and Miami, as would be expected simply on the basis of city size and degree of industrialization. Utility usage, which in this table includes only those power plants within the city limits, is highest in Baltimore and Philadelphia, older eastern cities where major, centrally located plants cannot be, or have not been, replaced by newer facilities in more remote locations.

Those heavily industrialized cities that have the largest emission problem due to fuel combustion are the cities that use significant quantities of coal for industrial purposes (Cleveland, Cincinnati) and/or power generation (Cleveland, St. Louis). Baltimore and Philadelphia, the two cities where the primary fuel for major point sources is residual fuel oil, are seen to have a lesser problem from fuel combustion, at least as judged by emission inventories.

Emissions from fuel combustion are tabulated separately for point and area sources in Table D-4, to the extent possible considering the different emission inventory formats available. Table D-5 presents the distribution of fuel use in residential housing units, the major portion of area sources. The absolute contribution of area source fuel combustion is determined by the fuel used and the climate, while the relative contribution is a function of the magnitude of other sources.

Table D-3. POINT SOURCE FUEL CONSUMPTION PATTERNS IN THE 14 CITIES

Cities	Industrial fuel usage[a]				Utility fuel usage[b]			
	% of total Btu			Total Btu x 10^{12}	% of total Btu			Total Btu x 10^{12}
	Gas	Oil	Coal		Gas	Oil	Coal	
Heavily industrialized								
Cleveland	63	4	33	101.1	0	1	99	31.8
Birmingham	77	9	14	56.9	0	0	0	0
Philadelphia	46	52	2	207.9	0	100	0	65.2
Baltimore	20	55	25	67.0	0	81	19	98.4
St. Louis	75	4	21	106.3	< 1	1	99	39.5
Cincinnati	54	6	40	48.0	100	0	0	5.8
Moderately industrialized								
Chattanooga	69	8	23	28.0	0	0	0	0
Denver	84	12	4	28.5	42	5	53	30.2
Seattle	4	95	0	31.8	0	100	0	0.7
Providence	35	65	0	19.2	0	100	0	13.1
Lightly industrialized								
Washington, D.C.	66	34	0	3.0	0	84	16	35.5
Oklahoma City	99	< 1	0	5.4	99	< 1	< 1	35.7
Miami	59	41	0	6.8	34	66	0	1.2
San Francisco	97	3	0	126.4	96	4	0	32.7

[a] Data for SMSA from reference 1.

[b] Data for plants within city limits from reference 2.

Table D-4. COMPARISON OF AREA SOURCE AND POINT SOURCE FUEL COMBUSTION EMISSIONS

Cities	Emissions, tons per year		
	Point source	Area source	Total
Heavily industrialized			
Cleveland	114,500	11,500	126,000
Birmingham	15,100	600	15,700
Philadelphia	9,200	7,900	17,100
Baltimore	3,200	2,100	5,300
St. Louis	66,100	900	67,000
Cincinnati	54,000	a	54,000
Moderately industrialized			
Chattanooga	6,900	200	7,100
Denver	500	7,100	7,600
Seattle	1,100	2,100	3,200
Providence	1,100	3,600	4,700
Lightly industrialized			
Washington, D.C.	3,900	1,600	5,500
Oklahoma City	1,500	300	1,800
Miami	1,400	a	1,400
San Francisco	200	600	800

[a] Not separately inventoried

Table D-5. RESIDENTIAL FUEL USAGE IN 1970 (PERCENT OF TOTAL DWELLING UNITS)[3]

Cities	Gas	Oil	Coal	Electricity
Heavily industrialized				
Cleveland	95	2	<1	2
Birmingham	88	1	5	6
Philadelphia[a]	46	49	2	3
Baltimore[a]	48	47	1	4
St. Louis[a]	83	12	2	3
Cincinnati	87	8	2	3
Moderately industrialized				
Chattanooga	22	6	9	63
Denver[a]	95	1	<1	4
Seattle[a]	28	44	<1	28
Providence	31	66	<1	2
Lightly industrialized				
Washington, D.C.	55	35	4	6
Oklahoma City[a]	93	<1	<1	7
Miami	35	9	<1	56
San Francisco[a]	92	1	<1	7

[a] SMSA – Data are for central county unless indicated as being for the SMSA

Process Emissions

Stack Emissions — In any city the magnitude of industrial emissions of particulates will depend on the degree of industrialization and the types of industry. Among the 14 cities studied, as shown in Table D-2, inventoried industrial process emissions are very significant in the cities with a high degree of intense industrial activity — St. Louis, Birmingham, and Cleveland, and to a lesser extent in Baltimore, Philadelphia, and Cincinnati. This breakdown of cities suggests that process emissions are higher in those cities where a substantial proportion of the heavy industry is iron and steel, with the associated coking and foundry operations; the detailed inventories confirm that these are the major contributors.

With the exception of Birmingham, where gas is burned, the correlation between the estimated emissions from fuel combustion and those from industrial processes is strong. This strong relationship is expected since heavy industrial processes and industrial fuel use would be related, and other factors such as the stringency of control programs could be expected to apply comparably to both categories. Thus these source categories are jointly responsible for that portion of the nonattainment problem attributable to traditional sources; that portion was judged to be of major importance in Cleveland, St. Louis and Birmingham.

Even in the less industrialized, generally cleaner cities, the industrial processes need to be assigned a share of the blame for nonattainment problems. In cities such as Miami, Seattle, and Oklahoma City, process emissions, while obviously much smaller in magnitude than in the industrial cities, are still a proportionally larger problem than fuel combustion sources. These emissions are generally from the type of small mineral industries — cement plants, asphalt plants, sand and gravel operations, and stone quarries — that necessarily are located in or near most urban areas, independent of the degree of heavier industrial activity.

Attempts to document reductions in inventoried industrial process emissions due to control strategies adopted under State Implementation Plans were successful in only a few cities. Most areas either did not maintain updated compilations of emissions or had inventories which were not comparable between years. This latter situation arose especially where control efforts were fairly recent as a result of the constantly developing program which was still identifying sources to be included in the inventories; therefore, previous data bases could not be considered complete.

In those areas where inventories were felt to be sufficient for trend determination, the stated reductions in industrial process (stack) emissions ranged between 90 percent in Oklahoma City to 1 percent in the Cleveland AQCR, with some areas reporting small increases in emissions due to growth. Generally, the reductions were around 20 to 40 percent. The types of industry that had the greatest reductions in total emissions were usually the same industries that were originally producing the most emissions (e.g., steel, coke, foundries).

Fugitive Emissions — One type of industrial emission which has been traditionally recognized but for which only minor control has been pursued to date is those emissions that are not vented out through stacks. In many operations, especially where materials handling is prominent, particulates are generated both inside and outside of plant facilities (but on plant property) in processes that are either ignored or insufficiently controlled so that particulate matter (and gaseous pollutants) are emitted into the working environment. For industrial processes that operate outdoors, such as coke ovens and rock crushing operations at quarries, these pollutants are directly emitted to the ambient air. When such processes are enclosed, the pollutants in the working environment may escape to the atmosphere through windows, doors, roof ventilators, or even unsealed cracks in walls. In any case, these pollutants, when they enter the outside ambient air, are defined as fugitive emissions.

Fugitive emissions may result from poor maintenance of process equipment, environmentally careless operations or difficult to control processes. For example, fugitive emissions can be the result of leakage from warped doors on coke ovens as well as the charging operation itself. Failure to observe proper occupational safety procedures in the design and placement of hoods over process areas causes excessive fugitive emissions as well as unnecessary exposures for the workers. Storage piles for sand and gravel, coal, grain, and other materials that are kept in the open become sources whenever a strong wind blows over them. Similarly, dirt and gravel parking lots and roads on industrial property can become sources of particulates due to either wind erosion or traffic.

Fugitive emissions are generally assumed to be small when compared with stack emissions; however, stack emissions have been coming under control, with as little as 1.0 to 0.1 percent of the previously uncontrolled emissions being allowed to escape to the ambient air. Therefore, the relative importance of fugitive emissions has been growing and they may now comprise a significant portion of nationwide emissions. For example, EPA has estimated that total fugitive emissions of particulate from electric arc furnace charging can be 5 to 50 times the total emissions of the furnace which are emitted from the stack downstream of control devices.[4]

In the course of this study, no attempt was made to survey the industry in each city to determine the amount of fugitive emissions or the extent of the impact. However, in the review of monitoring sites, local influences, including fugitive emissions, were noted. Of the 154 monitoring sites visited, 20 (13 percent) were felt to be subject to fugitive emissions. The type of source and exposure varied from monitor to monitor, but most sources could be classified as either rock and stone crushing, sorting and storage operations (including cement plants), or primary metals processing. A couple of sites were exposed to grain handling operations, and other sources included a junkyard, lumberyard, and a fabric filter bypass at a foundry. The impact that such fugitive emissions had on air quality levels are discussed later in this appendix.

Solid Waste Disposal

Of the several methods of solid waste disposal, incineration and open burning have traditionally been the most popular in urban areas and, therefore, significant sources of particulate emissions. The larger point sources of solid waste disposal emissions are the municipal incinerators and occasionally a large industrial installation, while the smaller residential/commercial incinerators and open burning in dumps are typically viewed as area sources.

The magnitude of particulate emissions from solid waste disposal in a city depends on the population of the city and the disposal methods commonly used. The estimates of emissions presented previously in Table D-2 show that the highest emissions occur in the larger cities and those cities where older municipal incinerators and/or numerous smaller incinerators were in operation — Cleveland, Birmingham, Philadelphia, Baltimore, St. Louis, and Providence. In several of the cleaner cities, municipal incinerators are among the largest point sources of particulate emissions.

While incineration emissions are not a major problem in many areas, they remain a source category where some improvements can be made since more attractive options exist. These can be either the development of modern recycling centers with the use of combustibles for fuel or, in smaller less urban areas, the use of landfills. The apparent trend in dealing with municipal waste is clearly in these directions, so that solid waste disposal emissions should continue to diminish as a significant concern in attaining clean air.

TRADITIONAL SOURCE CONTROL

An integral part of the impact that traditional sources may have on standards attainment is involved with the nature of the pollution control effort applied to them. Since fuel combustion, industrial processes and solid waste disposal have long been perceived as important sources of particulate emissions, the promulgation and enforcement of regulations and surveillance of these traditional sources have been the major activities of most air pollution control programs since their inception. While it was beyond the scope of this study to gather detailed information concerning these control efforts, a comparison of the stringency of regulations being applied and the types of surveillance/enforcement programs being pursued provided an important understanding of the role of control approaches in TSP standards attainment.

Regulations

Fuel Combustion — Regulations for particulate emissions from fuel combustion generally specify the allowable emissions in pounds per million Btu heat input or in grains per standard cubic foot of effluent air (gr/scf). Emissions from small area fuel combustion sources usually have more lenient emission standards than those of large facilities; often residential and small commercial furnaces and boilers with less than 1 million Btu per hour heat input are excluded from the regulations. Some agencies have different emission standards for the various types of fuel used, thereby allowing more stringent emission standards for combustion of cleaner fuels and less stringent standards for dirtier fuels whose emissions are more difficult to control. Design standards and operating practices may be specified, and permits to build and operate large sources may be required.

Among the 14 study cities, the stringency of fuel-burning regulations varies over the entire range of input rates (see Table A-2). The two cities with the most stringent regulations are Washington, D.C., and Baltimore; Baltimore's regulations are more stringent for installations up to 20 million Btu per hour input, and Washington's regulations are somewhat more stringent for higher input rates. The least stringent regulations of the 14 cities are those of St. Louis, although Cleveland's were essentially equivalent until July 1, 1975, when Ohio's regulations became effective. Regulations for Chattanooga and Oklahoma City are equivalent to those of St. Louis at low fuel input rates, but tighten to above-average stringency at high fuel input rates.

To understand how these regulations compared with those throughout the country, the regulations listed in the World's Air Quality Standards, Volume II,[5] were reviewed to find maximum and minimum stringency regulations. This review took the most and least stringent controls for each size category and, as such, the maximum and minimum controls do not necessarily reflect the controls in any one jurisdiction. The result of this review indicated that Baltimore, below 3×10^9 Btu/hr, and Washington, D.C., above that level, had the most stringent controls in the nation. The maximum and minimum control regulations are presented graphically in Figure D-1, along with the average of the 14 cities studied plus and minus one standard deviation, represented by the shaded area. For the purpose of comparison, the allowable emission level for the burning of solid fuels under reasonably available control technology (RACT) as defined in Appendix B of the EPA's Requirements for Preparation, Adoption, and Submittal of Implementation Plans (40 CFR 51) is also plotted on this figure.

The impact of a change in the stringency of a fuel-burning regulation can best be seen in Table D-6 where the maximum allowable emissions are given for various fuel inputs under the complete range of controls. While it may be impossible to enforce maximum stringent regulations in some areas due to problems of fuel availability, the tightening of regulations from minimum to average stringency can be expected to provide a 50 percent reduction in total emissions due to fuel combustion.

Table D-6. RELATIVE STRINGENCY OF PARTICULATE EMISSION STANDARDS FOR FUEL BURNING SOURCES — ALLOWABLE PARTICULATE EMISSIONS — IN $lb/10^6 Btu$

Relative stringency	Fuel input, 10^6 Btu/hr						
	0.01	1	10	100	1,000	10,000	100,000
Minimum	0.60	0.60	0.60	0.43	0.29	0.27	0.27
Average	0.35	0.35	0.33	0.21	0.14	0.12	0.12
Maximum	0.05	0.05	0.04	0.03	0.03	0.02	0.02

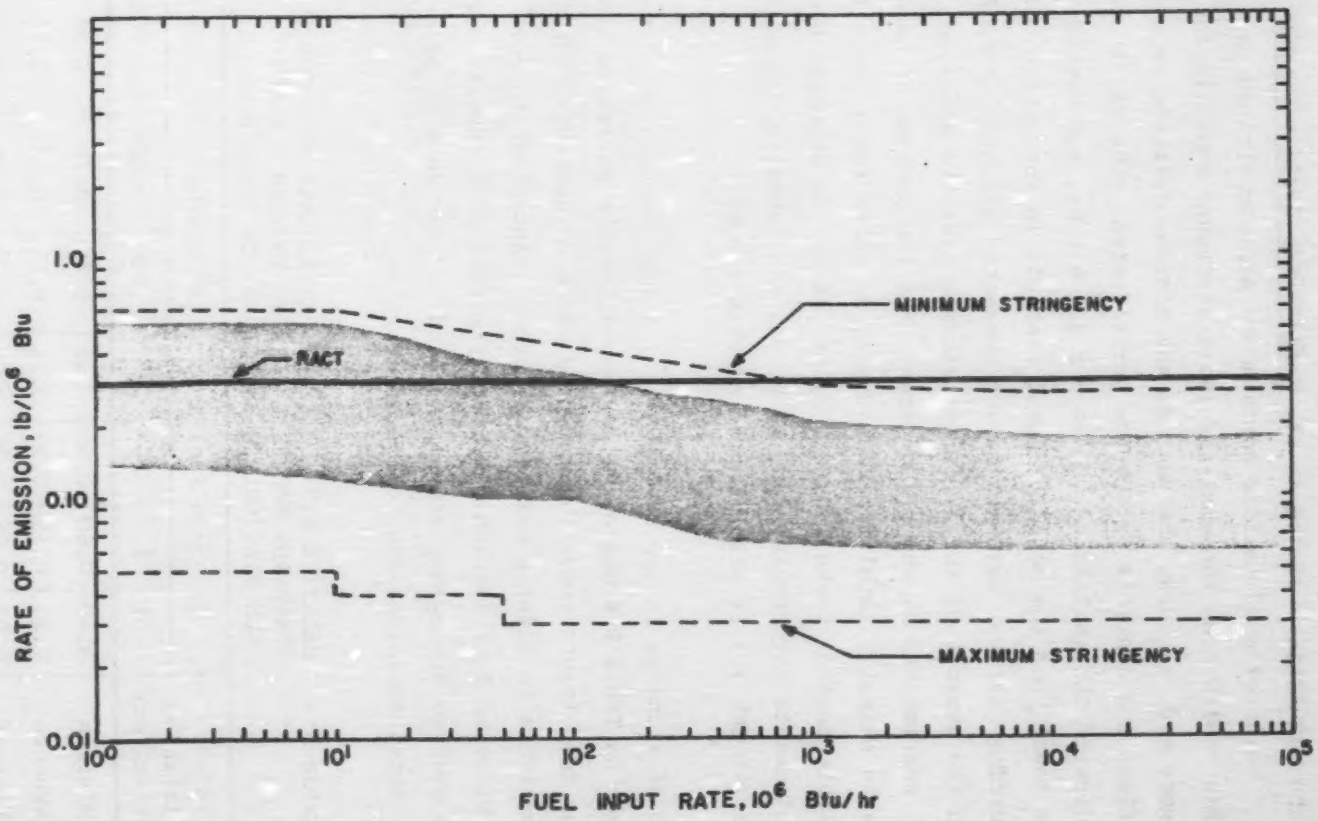

Figure D-1. Range of stringency of fuel combustion emissions regulations (shaded area represents the average of the regulations in the 14 study cities plus and minus one standard deviation)

Industrial Processes — Industrial processes result in either stack emissions, fugitive emissions, or both. Because of the different characteristics of these emission types and the degree of attention paid to each, they generally come under base regulations that are quite different. Regulations covering each of these industrial emission types are discussed in turn below.

Stack emissions — Stack emissions from industry are normally regulated by process weight rate regulations. In this type of regulation, a maximum emission rate, in pounds per hour, is established for a complete range of process feeds, also in pounds or tons per hour. The process feed is usually defined as the total weight of all materials entering the process excluding any fuels that are consumed (these would be covered under the fuel-burning regulations) or normal process air. The stringency of the regulation depends upon the maximum emission rate which can vary with the level of process feed. Different jurisdictions may define the process to be the complete transformation of the raw materials to the finished product or simply one step along the way. Similarly, the emissions may be measured at each stack or be the total for all stacks. Given the same emission rate for a certain feed, greater stringency results from more complete aggregation of steps and stacks.

All of the cities reviewed in this study have a general process weight rate regulation which is applicable to all industrial processes unless specifically exempted. Seven of the 14 cities (Chattanooga, Cincinnati, Cleveland, Oklahoma City, Providence, St. Louis, and San Francisco) have essentially the same standards, falling between the extremes of stringency exemplified on the low end by Seattle and on the high end (low emission rate) by Denver and Birmingham up to a process weight of 400,000 pounds per hour and, above that, by Philadelphia and the District of Columbia (see Table A-3).

As was done with the fuel combustion regulations, the regulations in the 14 cities were compared with those throughout the country using the World's Air Quality Standards, Volume II,[5] to find maximum and minimum stringency regulations. This review also combined the most and least stringent controls for each size category and does not reflect the controls in any one jurisdiction. The maximum and minimum are plotted in Figure D-2, along with the average of the 14 cities studied plus and minus one standard deviation, represented by the shaded area. Again, the allowable emissions from general processes as defined by Appendix B (RACT) is included on this figure for comparison purposes.

The impact of a change in the stringency of a regulation can best be seen in Table D-7 where the maximum allowable emissions are given for various process weight rates under different degrees of control. From this table, it is apparent that a significant percentage reduction in emissions can occur if large sources that are currently under minimum control are required to have average control. Changes in regulations from minimum to maximum stringency would reduce emissions from sources with process rates greater than 100,000 pounds/hour 70 to 90 percent. The same order of magnitude, on a percentage basis, would be seen for similar changes in the regulations for small sources (less than 1000 lbs/hr). The selection of such a control measure would be appropriate if there are large contributions to the emission inventory from these size categories.

Table D-7. RELATIVE STRINGENCY OF PARTICULATE EMISSION STANDARDS FOR GENERAL PROCESS SOURCES — ALLOWABLE PARTICULATE EMISSIONS (lb/hr)

Relative stringency	Process weight rate, lb/hr				
	100	1,000	10,000	100,000	1,000,000
Minimum	0.60	2.80	15.20	78.1	263.7
Average	0.52	2.59	11.09	42.1	63.3
Maximum	0.16	1.40	5.00	22.3	34.5

In addition to a general process weight rate regulation, many areas have process weight regulations for specific sources. For example, in Pennsylvania over 30 different types of industry are regulated for particulates

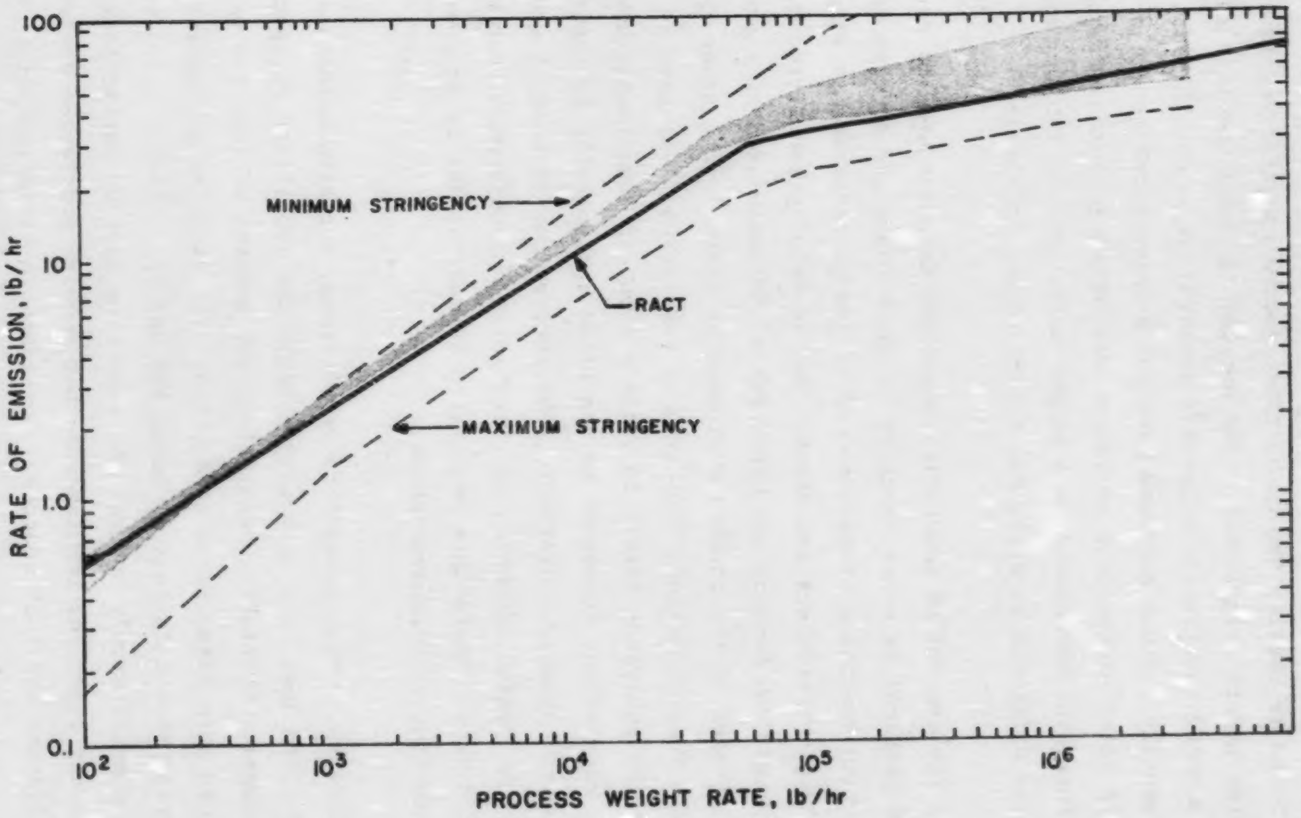

Figure D-2. Range of stringency of process weight rate regulations (shaded area represents the average of the regulations in the 14 study cities plus and minus one standard deviation) with several processes within each source type requiring different levels of control. As is usually the case, these source specific regulations supersede the general regulation. The purpose of these specific regulations is to require different allowable emission rates for the particular sources — usually a lower emission rate for sources which are major contributors to total particulate emissions and for which more stringent controls are possible, but sometimes a higher emission rate for sources which find controls difficult to apply and are not major problems.

Regulations for control of industrial emissions may also specify maximum permissible particulate concentrations in the exhaust gas or they may specify certain operating procedures and/or design requirements which serve to reduce particulate emissions. The scope of these latter regulations may range from banning certain types of furnaces used in a process to the designation of the control equipment or control efficiency that may be employed. To some extent, this type of regulation is easiest to enforce since the equipment itself is visible proof of compliance; however, as with any regulation, it cannot be patrolled continuously to ensure that it is not being bypassed. Similarly, the requirement of control equipment may provide the needed reduction in total emissions only when operated at maximum efficiency. Where this regulation is most useful is in control of fugitive emissions as discussed below.

Fugitive emissions — With respect to regulations, fugitive emissions are aptly named since they have generally escaped the imposition of specific control measures. Currently, regulations for control of fugitive emissions may be divided into three basic categories: (a) nonspecific regulations which recognize that emissions do occur and can be a nuisance; (b) regulations which quantitatively control the amount or type of particulate crossing the property line; (c) regulations that require particular control measures on different types of sources. Considerable variation exists within each of these categories among the various jurisdictions due to differences in wording, and many jurisdictions may use more than one type of regulation.

Under the first category of regulations, in which the problem of fugitive emissions is recognized, there are two major approaches. Many agencies will include in their regulations a general provision that bans any emission that is considered a nuisance or that endangers human health or welfare. Fugitive emissions can be controlled under this type of regulation, but complaints and the agency's judgment are needed to determine whether a source is a nuisance. The other form of "recognition" regulation is the requirement that reasonable precautions be taken to prevent particulate matter from becoming airborne. Most such regulations are modeled after the example regulations given in Appendix B of the EPA Requirements for Preparation, Adoption, and Submittal of Implementation Plans (40 CFR 51) which also lists measures that are considered to be reasonable. While a reasonable precaution regulation provides a better stance from which the air pollution control agency may operate, it still requires judgment in the determination of what is reasonable and often means that the problem must first be brought to the attention of the agency. Though this type of regulation may not be considered the most stringent, many agencies feel that it is sufficient for enforcement and yet allows them the flexibility to deal with each situation as it arises.

The second major type of regulation specifies the quality of air crossing the property line. The property line requirement appropriately separates consideration of the air quality within the plant property, which is under the control of the state or federal occupational health code, from the ambient air outside the plant property and under the jurisdiction of the air pollution control agency. The type and degree of property line restriction varies widely from opacity parallel to the property line (generally equal to Ringelmann 0 or 1) or simple prohibition on particles crossing the boundary, to specific quantitative limits on the amount, size, increase in concentration, or fallout resulting from particulates crossing property lines. The selection of appropriate limits on these parameters can effectively limit the TSP levels to prevent violations of the standard. Enforcement of this type of regulation is relatively easy due to its quantitativeness; however, with the exception of an opacity or total prohibition regulation, the determination of actual compliance involves the set-up and operation of a monitoring network that could be expensive. Restrictions on particle size may involve sizing instrumentation, and a regulation which sets a maximum increase in TSP concentration in the air crossing a facility necessitates having a monitoring network both upwind and downwind of the property.

The third category of regulations is sometimes considered a variation or extension of the reasonable precautions type of regulations. In this case, instead of stating that reasonable precautions are required of all sources, certain sources are singled out for control and specific control measures may be required. Sources often controlled this way are hot mix asphalt plants; sand, gravel, and stone crushing operations; cement plants; concrete batching; mica and feldspar processing; quarrying and mining; coal handling; and general earth-moving activities such as road or building construction. In addition to requiring the application of certain control measures including the use of waters, chemical stabilizers, oil, or covers and the installation of hoods, fans, fabric filters, and other control equipment, these regulations may specify standard operating procedures, as in charging of coke ovens, or maintenance requirements for process equipment and buildings so that they are properly sealed and vented through exhaust systems. Of the three major categories discussed, this one is felt to be most effective and the easiest to enforce. Not only can the regulatory agency quickly determine compliance with the regulations but the source is aware of exactly what control is required of it. Should the source feel that another control could be as effective, the burden of proof would lie with the source.

The type of regulations for control of fugitive particulate matter than were applied in the 14 study cities are summarized in Table A-5. Almost all cities had some form of reasonable precaution requirement, and many of them also could control fugitive emissions under a nuisance regulation. Five areas prohibited particulate matter from crossing property lines and three restricted the opacity of the plume. Cleveland set a maximum concentration of 500 $\mu g/m^3$ (1-hour average) for particulates crossing the property line, and the Commonwealth of Pennsylvania limits the concentration to 150 particles per cubic centimeter above the background concentration. Specific sources are controlled in only a few areas and a limited number of sources come under control.

The regulations generally do not make a distinction between fugitive dust (see Appendix E) and fugitive emissions. However, reasonable precaution type regulations primarily deal with fugitive dust, while regulations for specific sources are usually directed toward fugitive emissions. A property line standard may be made applicable to both types of emissions.

As part of this study, regulations for 76 jurisdictions were reviewed, including those for all 50 states, the 14 TSP cities, and several other cities and counties. Table D-8 is a summary of the regulatory approaches to fugitive particulate emissions used by the various jurisdictions; as might be expected, there is considerable variation within the categories due to differences in wording and varying degrees of detail. However, the approaches remain essentially the same. Figure D-3 shows the geographic distribution of the principal categories.

About two-thirds of the jurisdictions have a regulation requiring that reasonable precautions be taken to prevent particulate matter from becoming airborne. In addition, possible sources and appropriate measures that would consistitute reasonable precautions are sometimes enumerated. It is in this respect that the greatest variation among the regulations appears, since many of the jurisdictions only list possible controls or nothing at all. About 8 percent of the jurisdictions regulate fugitive particulate emissions on a source-by-source basis without a reasonable precautions section.

Table D-8. SUMMARY OF REGULATIONS APPLICABLE TO FUGITIVE PARTICULATES

Regulation type	Number of jurisdictions		
1. Reasonable precautions required	48		
(a) reasonable precautions regulation alone		39	
- including restrictions on fugitive emissions from buildings			6
- including a property line restriction			6
(b) reasonable precaution regulation with additional restrictions on specific sources		9	
- including a property line restriction			2
2. Regulation by specific source	8		
3. Nuisance regulation alone	4		
4. No regulation	5		
5. Other	11		
(a) restriction on particulate concentration at property line		5	
(b) restriction on the size of particulates at property line		2	
(c) fallout limitation		3	
TOTAL	76		

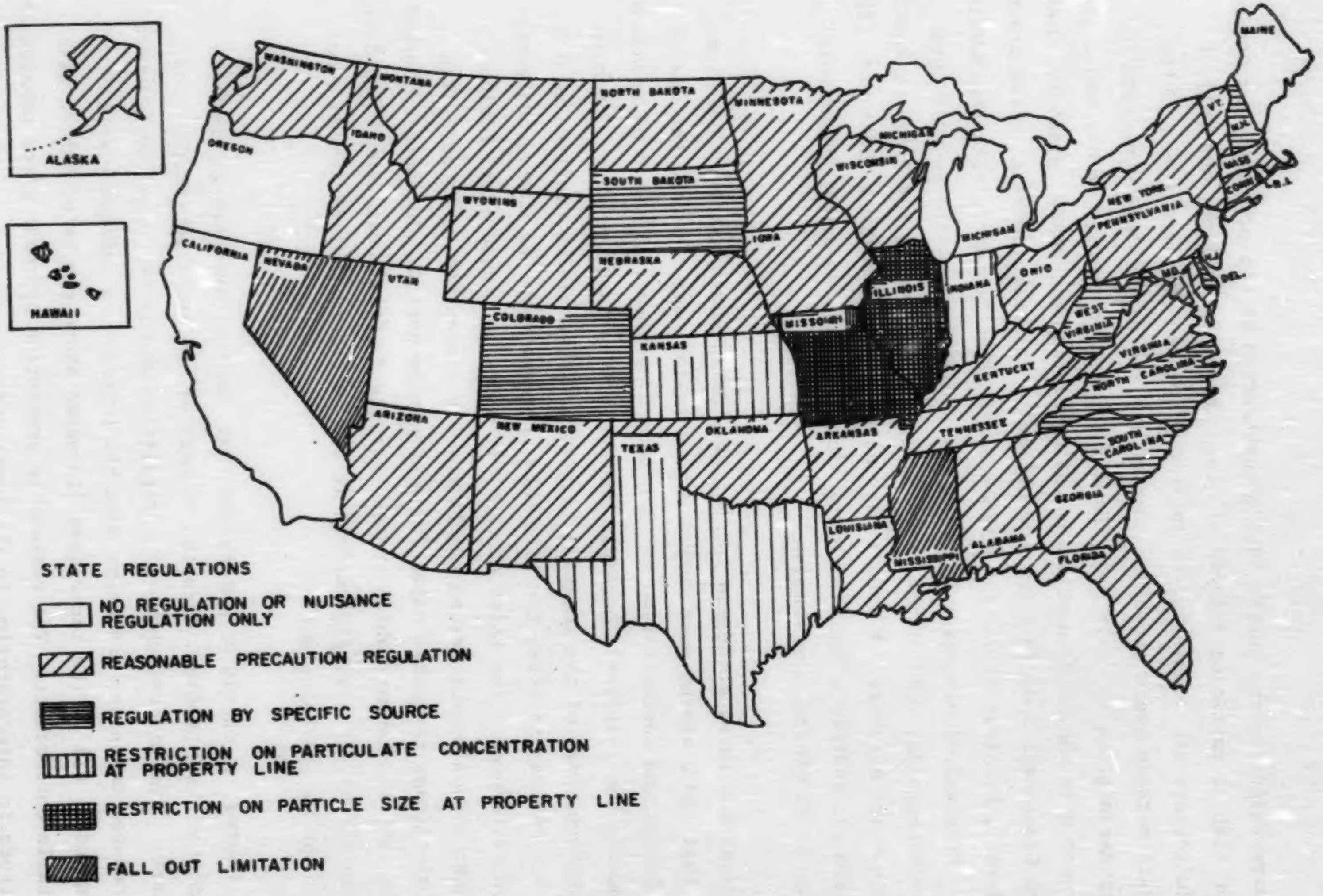
ALASKA
HAWAII
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
MD.
DEL.
N.J.
PENNSYLVANIA
NEW YORK
VT.
N.H.
MASS
CONN
R.I.
MAINE
STATE REGULATIONS
NO REGULATION OR NUISANCE REGULATION ONLY
REASONABLE PRECAUTION REGULATION
REGULATION BY SPECIFIC SOURCE
RESTRICTION ON PARTICULATE CONCENTRATION AT PROPERTY LINE
RESTRICTION ON PARTICLE SIZE AT PROPERTY LINE
FALL OUT LIMITATION

Figure D-3. Geographic distribution of categories of regulations governing fugitive particulates

Restrictions on the particulate concentration at the property line and on the size of particles allowed to cross the property line, and fallout limitations are summarized in Table D-9 for ten jurisdictions. Three basic methods are employed in instituting the particulate concentration standards given in Table D-9. Hawaii and Kansas specify an allowable increase over the background or upwind concentration; Texas, Missouri, Omaha and Cincinnati specify a maximum allowable concentration; and three states (Hawaii, Mississippi and Nevada) have a fallout standard, with the Hawaii and Mississippi standards being expressed as an allowable increase over the background. Use of the high-volume air sampler is specified by Hawaii, Kansas and Missouri. Missouri also makes use of a soiling index and, like Illinois, restricts the size of particles allowed to cross the property line to 40 microns and smaller.

Indiana has three standards for fugitive particulate matter. The first is that the downwind particulate concentration cannot exceed the upwind or background concentration by more than 67 percent. The second standard concerns the respirable particle content of the fugitive dust. If more than 50 percent of the emission is respirable particles, defined as 0.5 to 6.0 microns in size, the allowable increase over the upwind concentration is reduced. The third standard is that the ground-level ambient concentration cannot exceed the background concentration by more than 50 micrograms per cubic meter for a 60-minute period. In addition, there is a visible standard which states that the fugitive dust cannot be visible crossing the property line unless it can be proved that the three standards above are being met.

In summary, it should be emphasized that the fugitive emission problem is mostly a local problem, affected in part by the local meteorology and terrain. The effectiveness of a regulation should be judged by how much it reduces emissions and helps meet the primary and secondary ambient standards. All of the techniques discussed above can be effective with suitable enforcement. The reasonable precaution approach gives considerable latitude in interpretation to the local enforcement agency. It is beneficial

Table D-9. PROPERTY LINE STANDARDS

Jurisdiction	Standards
Hawaii	150 $\mu g/m^3$, above upwind concentration, 12-hour average 3.0 g/m^2, fallout above upwind concentration, 14 day period
Kansas	2.0 mg/m^3, above background concentration, 60 minute average
Texas	100 $\mu g/m^3$, 5-hour average 200 $\mu g/m^3$, 3-hour average 400 $\mu g/m^3$, 1-hour average
Omaha	500 $\mu g/m^3$, 60 minute average
Missouri	80 $\mu g/m^3$, 6 month geometric mean 200 $\mu g/m^3$, 2-hour arithmetic mean 0.4 coh/1000 linear feet soiling index, 6 month geometric mean 1.0 coh/1000 linear feet soiling index, 8-hour arithmetic mean > 40 µm
Mississippi	5.25 g/m^2, fallout above background
Nevada	2 $tons/mi^2$, 24-hour period
Illinois	> 40 µm
Cleveland	500 $\mu g/m^2$, 60 minute average
Indiana	See text

if the reasonable precautions are clearly defined. Regulation by specific source is effective near major sources and where the principal contributors can be identified. This approach would seem to have the least amount of difficulty in enforcement. Standards for particulate concentration or fallout at the property line are of particular value in controlling emissions from specific industrial or commercial sources, but require sampling to determine compliance.

Solid Waste Disposal (Incineration) — Regulations on particulate emissions from solid waste disposal by incinerators specify the allowable emissions in pounds per 100 pounds of refuse charged for different size incinerators, in pounds per hour of operation, or in grains per standard cubic foot of effluent gas per minute. Some jurisdictions also have a design standard which requires incinerators to be of the multiple-chamber, indirect feed type with gas washers, and some have operating standards. Chattanooga's operation standard requires incinerator operators to be knowledgeable on correct incineration practices by testing and licensing them. Small incinerators are banned entirely in some jurisdictions — Baltimore and Philadelphia have banned incinerators with charging capacities of less than 10,000 pounds per hour. Regulations have banned open burning almost everywhere except for certain purposes — such as campfires or fire-fighting training — which will not substantially affect particulate emissions because of their small size and low frequency. Typically, cities will allow open burning only when a permit has been issued by the air pollution control agency, only if certain allowed types of materials will be burned, and only when pollution potential is low.

The range of variation in the stringency of the incinerator emission regulations for the 14 study cities is shown in Table A-4. Baltimore has the most stringent regulation of the 14 cities by far, while Chattanooga's is the least stringent. The stringency of the regulations for open burning with permits can be varied according to the needs of the jurisdiction by reducing the number of permits issued and restricting the areas where open burning with a permit can take place.

Surveillance, Compliance and Enforcement Programs

Although the stringency of the regulations that are being applied and enforced is obviously important in determining the reductions in particulate emissions actually obtained, equally important are the enforceability of the regulations, the strictness of the enforcement, and the manner in which compliance is determined. As discussed above, the enforceability of regulations affects the ease and speed with which emissions are controlled and can vary widely with the types of regulations in effect. For example, in dealing with numerous small incinerators, agencies find a standard requiring specific equipment (e.g., multichamber, indirectly fed incinerators) much easier to enforce than an emission standard; in dealing with coke ovens, Birmingham has found most efficient an operation standard that specifies maintenance and operating conditions; in dealing with fugitive emissions, a source-specific regulation is considered much more effective than a nuisance regulation.

Similarly, the achievements of control programs depend on the matching of enforcement activities to the nature of the particulate emissions problem. Among the 14 cities, the largest actual emission reductions from traditional sources have been achieved in those cities where surveillance and enforcement programs are comprehensive and vigorous. The activities of such programs generally include the following: constant surveillance and patrols, frequent inspections of problem sources, a general knowledge of all of the traditional sources, rigorous compliance determination, prompt action when a violation or upset occurs, issuance of compliance orders that are strict yet reasonably attainable in the opinion of an appeals board, and strict enforcement of compliance schedules.

Almost all pollution control agencies conduct visual surveillance of the traditional sources — some on a routine basis and some only in response to complaints. In addition, almost all agencies respond to complaints and investigate their causes. More detailed source inspections are performed by most agencies, but the frequency and detail of inspection varies, as does the size of the sources normally inspected. The detailed source inspections generally consist of walking through a plant, looking over the processes and air pollution control devices, and checking records. Some agencies inspect sources only when a permit to operate or alter is issued or renewed. Other agencies inspect the larger sources and the sources with problems or variances more frequently, as much as two or three times a month, and the smaller sources less frequently, depending on size and problems. Only a few agencies (of those in the 14 cities) require stack tests of sources at regular intervals; the stack test is either performed by the agency or, more typically, by the source or its consultants under the supervision of the agency.

The primary purpose of the surveillance and enforcement programs is the determination of compliance. Determination of the compliance of sources with the regulations varies greatly in rigor, ranging from simple calculations of emissions, based on emission factors and reported control efficiencies, to more elaborate walk-through inspections of facilities and equipment and stack tests of emissions. In the State of Illinois, a performance bond may be required of sources which are installing control equipment — the bond to be forfeited if a stack test shows that the source is not in compliance by its scheduled date of compliance.

Since the compliance date toward which most control programs were working — May 31, 1975 — had recently passed at the time of the city visits, the agencies could provide information on the status of compliance and would also indicate how the determination of compliance was made. While some agencies had extensions or initially later compliance dates so that substantial reductions in emissions were expected in the future, most agencies in the study cities reported that compliance of particulate sources was nearly complete with some sources still under specific compliance plans.

However, reports of full or near compliance may not actually mean that all traditional sources are in strict compliance with the regulations. While not a major purpose of the present study, some understanding of the methods used for compliance determination was obtained during discussions on overall compliance status. Typically, compliance of a source is determined when a permit to operate is issued or renewed, when new equipment is installed, or at other points. However, all too often it appears that agencies will assume, without checking, that the source continues to be in compliance even though control equipment may be inoperative or deteriorating, process loads may be changed, or other difficulties may be encountered. Beyond this concern with follow-up, there was also some apparent difficulty with the rigor of the compliance determination techniques themselves. Only a few of the agencies visited conduct or require actual stack tests and then not on a routine basis. More commonly, compliance is determined on the basis of walk-through inspections and theoretical calculations based on process loads, emission factors, control efficiency specifications, and similar data. While this is obviously appropriate for some sources and control measures when done by well-trained agency personnel, it is equally inappropriate for other, more complex sources with untried control technology, particularly when done by inexperienced agency personnel. The overall impression was that the level of effort in compliance determination was such that, frequently, little confidence could be placed in many agencies' determinations of strict compliance with their regulations.

AIR QUALITY IMPACT

While the above discussions have focused upon particulate emissions from traditional sources — fuel combustion, industrial processes, solid waste — and the control programs affecting them, a primary objective is to develop an understanding of the impact that traditional sources are having on TSP levels. Specifically, it is important to place traditional sources in a proper perspective with respect to the problem of standards attainment; i.e., how do changes in emission levels affect air quality; what is the current contribution of traditional sources to TSP levels above the standards; what further reductions in TSP may be expected under additional control?

Because of the wide variety of information available and the complexities of the situation, several different types of analyses were conducted on the data collected in the 14 study cities. Each of these analyses is presented separately below, but together they serve to provide the assessment of the traditional source impact on TSP standards attainment given in the conclusion and summarized in Section III.

Current Emissions

In general, the impact of traditional sources on nonattainment depends very heavily on the nature of the urban area in question. The 14 case study areas included both cities where traditional sources totally dominated the picture and cities where they are not and probably never have been a major share of the problem. Based on analysis of aggregate emission inventories and compliance trends, the status of traditional sources in the urban areas studied have been categorized as follows:

I Traditional sources are still a problem in (1) Birmingham because many major sources are still on compliance schedules and another 80 percent reduction in traditional emissions is expected; (2) Cleveland because little enforcement has been pursued and most sources are neither in compliance or on schedules; and (3) St. Louis because, although most sources (on the Missouri side) are determined to be in compliance, the regulations are not very stringent.

II Major traditional emissions have been significantly reduced to the point where they are no longer totally dominant in Philadelphia, Baltimore and Cincinnati due to their long-standing control programs. However, some further reduction of traditional source emissions is possible along with control of nontraditional sources.

III Moderate emissions are reasonably well controlled in Chattanooga, Seattle, Providence, and Denver.

IV Traditional sources were likely never a very serious problem in Miami, Oklahoma City, and San Francisco. Washington, D.C., no longer has much of a problem with traditional sources.

For the purpose of assessing the TSP attainment problem this type of breakdown provides an indication of the further reductions that may reasonably be expected through traditional source control; i.e., those cities in the first category listed above (major uncontrolled traditional emissions) should be able to reduce traditional emissions (and TSP levels) at least to those currently in the second category (major controlled traditional emissions). If the cities in the first two categories are expected to be no dirtier than the other cities, almost all of which are violating the standards, then all cities in the first two categories would have to reduce their traditional source emissions to the levels in the bottom two categories.

While the most direct relationship between traditional source emissions and TSP concentration is one of increasing TSP concentration with increasing emissions, another simple parameter that addresses the distribution of sources in an area and the dispersion of emissions is emission density (tons per year per square mile). Table D-10 provides a listing of the total tons per year and emission density for the cities under the above classification and also gives the citywide TSP concentration with the non-urban particulate levels and sulfate/nitrate excess subtracted out. These TSP contributions were removed to account for the changes that occur simply due to different locations around the country (nonurban levels) and those sulfate and nitrate TSP levels in the city (above those in nonurban areas). (See Section III for a detailed explanation of the numbers used in this calculation.) The selection of areas for the calculation of emission densities was made on a judgmental basis considering the distribution of major sources, the ambient monitoring network, and the air basin.

As may be seen in Table D-10, considerable scatter and overlap exists between the total emissions, the emission densities, and the air quality levels given, due in part to differences in dispersion characteristics of the areas. However, on an average basis, there is apparently no real difference between those areas with no major industry (Category IV) and

Table D-10. COMPARISON OF TRADITIONAL SOURCE EMISSIONS, EMISSION DENSITIES, AND TSP LEVELS IN THE 14 STUDY AREAS

Cities	Tons per year	Tons per year per square mile	Citywide TSP minus nonurban and secondary urban excess
Category I			
Birmingham	110,000	488	60
Cleveland	210,000	335	84
St. Louis	190,000	411	55
Average	167,000	411	66
Category II			
Baltimore	23,700[a]	240	56
Cincinnati	56,100	135	42
Philadelphia	31,600	245	45
Average	37,100	207	48
Category III			
Chattanooga	10,300	88	31
Denver	9,700	60	83
Providence	7,800	30	28
Seattle	7,300	37	42
Average[b]	8,500	52	34
Category IV			
Miami	8,000	30	34
Oklahoma City	2,600	2	40
San Francisco	4,800	60	32
Washington, D.C.	5,600	92	31
Average	5,250	46	34

[a] Includes both Baltimore City and Baltimore County.

[b] Denver is not included in these averages because of its adverse, complicating meteorology.

those cities with a moderate amount of industry (Category III) but primarily under control. Cities that are fairly heavily industrialized but have most sources under compliance with moderately stringent regulations average 10 to 15 $\mu g/m^3$ higher than the lower two categories; those cities that still need to bring major sources under compliance (Category I) average 30 $\mu g/m^3$ higher. When a regression analysis was applied to these sets of numbers (excluding Denver), the following equation was derived ($r = 0.769$; standard error = 10.5 $\mu g/m^3$):

$$TSP_{cw} = 7.6 \times ED + 31.9$$

where TSP_{cw} = the citywide TSP level above the nonurban and secondary urban excess levels, in $\mu g/m^3$

ED = the emission density, in 100 tons/yr/sq mile.

The average values of emission density and TSP levels for each category of cities are plotted in Figure D-4, along with the ranges, which reflect the differences that arise because of topography and meteorology. This figure indicates that even the cleanest cities (with respect to traditional sources) are still 30 to 40 $\mu g/m^3$ above the nonurban levels. Therefore, with nonurban levels ranging between 20 to 35 $\mu g/m^3$, only a very few cities, with favorable meteorology, can be expected to meet the secondary annual standard (guide of 60 $\mu g/m^3$) on a citywide basis through control of traditional sources. Since these levels are citywide averages, all cities of the size considered here can be expected to have at least one site exceeding the secondary annual standard. At the same time, this figure indicates that control of traditional sources is warranted and necessary to meet the primary annual standard (75 $\mu g/m^3$) when traditional source emission densities are greater than 100 to 200 tons/year/square mile.

Modeling Studies

Aside from considering the impact of the total traditional sources on TSP air quality, the relative contributions of each of the major categories

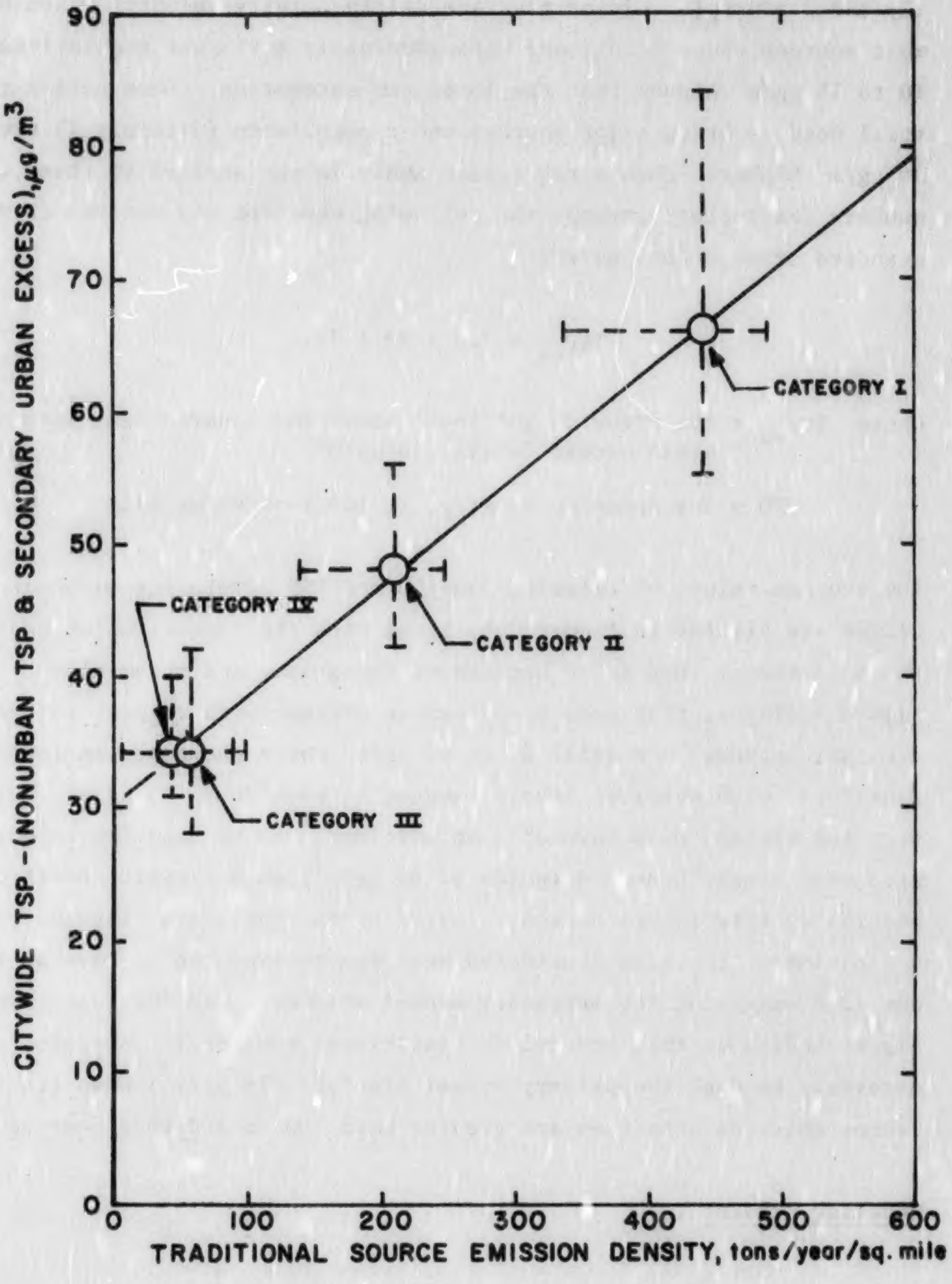

Figure D-4. Traditional source emission density versus above nonurban TSP levels

need to be understood. While the relative contributions of each of the categories to the total impact from traditional sources may be expected to be in direct proportion to the emission inventories, the different types of emissions (process versus combustion), the spatial distributions, and the stack heights can have an effect on the eventual contributions.

As part of this effort to assess the attainment of the TSP standards, modeling studies were performed by EPA for three of the 14 cities - Cincinnati,[6] Cleveland,[7] and St. Louis.[8] The studies used past and current emission data to determine the emission sources which were most affecting the TSP concentrations recorded at certain selected TSP sampling sites. The use of modeling, as opposed to the rollback technique, allows the position (i.e., distance and height) of sources with respect to the sampling site to be taken into account The model predicted the air quality impact separately for point sources (divided into industrial process, fuel combustion, and solid waste incineration) and for area sources. Because all of these cities had over 97 percent of their inventories in traditional sources, the assumption was made that the area source contribution came primarily from area source fuel combustion.

Table D-11 presents the results for the three cities, showing the range of percentage contributions of the different source categories to the above-background concentrations for all modeled sampling sites in a city and also to the total traditional source inventory for each area. The closest correlation on the basis of source category is in solid waste, which is a small part in any of the cities; on a city-by-city basis, the highest overall correlation was in St. Louis. In Cincinnati and Cleveland, the industrial contribution is apparently larger than would be predicted solely from the emission inventories. Two explanations for this are evident: (a) the monitoring sites for these cities were more often located in industrial areas so the sites evaluated would have a greater impact from industry; (b) the contribution from industrial emissions to the calculated TSP levels is greater because of the effect of parameters such as stack height and location throughout the city.

Table D-11. MODELED TSP CONTRIBUTIONS VERSUS CONTRIBUTIONS FROM THE INVENTORY FOR TRADITIONAL SOURCES IN THREE CITIES

Source category	Cincinnati		Cleveland		St. Louis	
	Percent contribution above background TSP[a]	Percent of traditional sources	Percent contribution above background TSP[a]	Percent of traditional sources	Percent contribution above background TSP[a]	Percent of traditional sources
Fuel combustion	65 – 85	96	21 – 42	60	23 – 65	35
Industrial	15 – 34	3	57 – 78	37	35 – 76	63
Solid waste	< 1	1	1 – 4	3	< 1	2

[a] Background TSP is the value calculated in the model for the TSP level that cannot be explained due to the inventoried sources. The values for each of the cities are: Cincinnati – 58 μg/m^3, Cleveland – 44 μg/m^3, St. Louis – 32 μg/m^3.

The impact that fugitive emissions had on individual monitors could also be determined from these modeling studies. Where the model was found to provide large underpredictions for certain sites, fugitive emissions (and other local sources) were prominent influences. These underpredictions were usually in the range of 15 to 40 $\mu g/m^3$, centering around 25 $\mu g/m^3$. This range agrees with the analysis presented later under the discussion of site analysis.

Microscopic Analysis

In addition to the modeling studies, a number of hi-vol filters were analyzed microscopically for each of the 14 cities to determine the components of the collected particulates. The component analysis could then be used in an attempt to identify the sources of the particulates. One category used during the analyses was combustion products, including oil soot, coal soot, and glassy fly ash. Table D-12 shows the citywide composite summary of oil and coal combustion products (average percent by weight) determined during the filter analysis which gives a rough idea of the relative impact of fuel combustion on the weight of particles (larger than 1 μm) collected during sampling. The results show that coal combustion products (coal soot and glassy fly ash) are a relatively important portion of TSP samples in Chattanooga, Cincinnati and Cleveland where coal usage is substantial. Oil soot is relatively important in Providence and Washington, D.C., which are primarily residential cities where oil is an important fuel. Comparing the composite combustion products data with fuel usage data for the 14 cities showed a correlation between percent oil soot and percent of homes using oil for space heating ($r = 0.699$) and a stronger correlation between percent coal combustion products and percent of industrial fuel usage being coal ($r = 0.826$). A comparison of residential coal usage with coal combustion products showed no correlation.

Table D-12. PERCENT WEIGHT OF SELECTED FUEL COMBUSTION PRODUCTS IN 14 CITIES[a]

City	Oil soot	Coal combustion products		
		Coal soot	Glassy fly ash	Total
Baltimore	9	5	6	11
Birmingham	4	2	3	5
Chattanooga	7	14	5	19
Cincinnati	9	6	24	30
Cleveland	9	12	15	27
Denver	0	1	1	2
Miami	4	3	2	5
Oklahoma City	5	2	1	3
Philadelphia	8	2	5	7
Providence	13	2	2	4
St. Louis	1	< 1	2	< 3
San Francisco	3	9	1	10
Seattle	10	6	< 1	< 7
Washington, D.C.	13	3	7	10

[a] Data from composite of microscopic analysis of selected filters

Monitoring Site Analysis

A major part of this study was the visiting and reviewing of monitoring sites in the study cities to determine the possible impacts on the TSP levels being measured. Over 150 such hi-vol sites were reviewed and the data compiled provided important information on the relative contributions of the various source sectors in different neighborhoods and different types of cities.

Fugitive Emissions - One of the principal objectives and results of the monitoring site reviews was to determine the impacts of fugitive emissions and fugitive dust emission (see Appendix E). In the review of monitoring sites, local influences, including fugitive emissions, were noted. Of the 154 monitoring sites visited, 20 (13 percent) were felt to be subject to fugitive emissions. The type of source and exposure varied from monitor to monitor but most sources could be classified as either rock and stone crushing, sorting, storage operations (including cement plants), or primary metals processing. A couple of sites were exposed to grain handling operations and other sources included a junk yard, lumber yard, and a fabric filter bypass at a foundry.

Though the total level of fugitive emissions from a process may be small in comparison with the stack emissions, the low height at which they emanate means that very little dilution occurs before they reach the breathing zone of those residing or working in areas near the facility. Even if the emission is only the air inside of a building escaping to the outside, the levels can be quite high. The maximum allowable 8-hour average concentration for nuisance dusts in an industrial environment is 15 mg/m^3 (5 mg/m^3 respirable), as set by the Occupational Safety and Health Standards. This is almost 60 times the primary 24-hour air quality standard for particulates.

Although the degree of impact on ambient levels is dependent on the total mass of emissions, the extent of the impact depends upon the size of the particles. Many operations which are primarily materials handling, crushing, or sorting processes generate particles that are fairly large. These particles may be expected to fall out or be deposited close to the source, probably within a radius of a half mile. Other fugitive emissions, however, may contain fumes or combustion products which are much smaller, can remain suspended for a long period of time, and therefore have a much wider range of impact.

Since fugitive emissions are intermittent and local in nature, they have their greatest impact over short time periods. The data collected in this study indicated that in Philadelphia in 1974, the highest 24-hour TSP level found was 624 $\mu g/m^3$ at a site near a gravel storage pile and a grain loading operation; the filter was reported to contain high levels of grain dust. This one site, sampling once every 6 days, was responsible for half of the violations of the primary 24-hour standard reported for all of the monitors sampling in the City of Philadelphia. In Oklahoma City, a special field study of fugitive emissions was conducted by the Division of Environmental Health. Short-term concentrations on the premises of a concrete and asphalt plant ranged from 121 to 1140 $\mu g/m^3$ while the TSP levels at a monitor outside the plant ranged from 43 to 743 $\mu g/m^3$. When the outside monitor was upwind of the plant, it averaged 78 $\mu g/m^3$ (11 percent of in-plant concentrations); downwind of the plant, it averaged 200 $\mu g/m^3$ (42 percent of in-plant concentrations).

Since fugitive emissions are associated with industry, most of the exposures were found in industrial areas; in fact, 32 percent of all sites visited in industrial areas were subject to fugitive emissions. Because major differences exist in the placement and exposure of monitors, a comparison of the average value at sites near fugitive emissions and at those which were not so obviously exposed in each city gave a range of values from over 50 $\mu g/m^3$ higher to 10 $\mu g/m^3$ lower at the fugitive emission sites on an annual average basis. However, based on the visits to the monitoring sites it was possible to make judgemental groupings of monitors to reflect comparable industrial exposures with and without fugitive emissions. Then the sets of monitors exposed to fugitive emissions averaged 25 $\mu g/m^3$ higher than comparable monitors in the same city not noted for fugitive emissions. The effect of this average difference of 25 $\mu g/m^3$ can be seen when the distribution of values is studied. As shown in Table D-13, when the TSP levels at the industrial monitors are distributed in 25 $\mu g/m^3$ intervals above the primary standard, those sites in industrial areas that are influenced by fugitive emissions are the only ones that had annual means more than 150 $\mu g/m^3$, and all of these monitors were above the primary annual standard of 75 $\mu g/m^3$.

Table D-13. DISTRIBUTION OF ANNUAL MEANS AT INDUSTRIAL SITES WITH AND WITHOUT FUGITIVE EMISSION INFLUENCES

TSP concentration, $\mu g/m^3$	Number of industrial sites	
	With fugitive emission influence	Without fugitive emission influence
151 - 175	3	0
126 - 150	4	7
101 - 125	3	9
76 - 100	3	9
≤ 75	0	3
Total	13	28

Total Impact — The review of the monitoring sites also allowed an estimation of the total impact of emissions from traditional sources, especially major point sources, by comparing the TSP concentrations at different sites in the highly urbanized, industrial cities to those in areas with low emission levels. For example, in Miami's residential areas, where industrial emissions are low and space heating emissions are almost nonexistent, the average level is 50 $\mu g/m^3$. This type of difference in TSP levels has already been demonstrated in Table D-10 in which the heavily industrialized cities were shown to have citywide TSP levels 20 to 50 $\mu g/m^3$ higher than those in lightly industrialized areas.

Table D-14 is used to summarize and compare the TSP levels in different neighborhoods of the study cities among the industrial groupings. As was done in Table D-10, the nonurban levels were subtracted from the neighborhood values for each city and the resulting levels were averaged for each of the categories defined above. Again, the TSP levels are highest in the heavily industrialized areas and lowest in the lightly industrialized areas when compared on a neighborhood basis. However, while the percent

Table D-14. TSP LEVELS AND STANDARDS VIOLATIONS BY CITY CATEGORY

City category	TSP concentration above nonurban levels, µg/m^3						Percent of sites above standard			
	Residential		Commercial		Industrial		Annual		24-hour	
	Range	Average	Range	Average	Range	Average	Primary	Secondary	Primary	Secondary
I	29 to 45	36	41 to 86	61	74 to 113	92	55%	84%	26%	90%
II	26 to 30	27	36 to 48	41	58 to 71	65	38%	69%	16%	45%
III[a]	18 to 21	20	29 to 42	35	54 to 62	58	19%	33%	7%	30%
IV	17 to 26	23	31 to 49	37	NA	NA	16%	35%	33%	70%

[a] Denver is not included in these numbers because of its adverse, complicating meteorology.

of monitors with violations of the annual standards decreases as one goes from Category I to Category IV cities, this pattern is not totally consistent for the violations of the 24-hour standards. Therefore, 24-hour standard violations can logically be assumed to be influenced to a large extent by other than total emissions; e.g., meteorology, monitor siting.

These data indicate that the traditional sources were still adding about 5 μg/m^3 to levels in residential neighborhoods in those cities where major traditional emissions had been significantly reduced; the lack of control of major traditional emissions (Category I) made residential levels another 10 μg/m^3 higher. Similarly, levels in commercial neighborhoods of cities in Category II were about 5 μg/m^3 higher than in Categories III or IV but Category I cities had TSP levels in commercial neighborhoods averaging 20 μg/m^3 higher than Category II cities. The same pattern is followed in the industrial neighborhoods with Category II cities averaging 7 μg/m^3 more than Category III cities and 27 μg/m^3 less than Category I cities.

The consistent increase in TSP levels, regardless of neighborhoods, between Category II and Category III and IV cities suggests that the problem in Category II cities is more likely due to areawide sources that have had insufficient attention while the major point sources were being controlled. Such sources may be fuel combustion, small industries scattered around the city, or nontraditional sources that may be related to city size and industrial activity. The increasing difference in TSP levels between Category I and Category II cities as one goes from residential neighborhoods to industrial neighborhoods indicates that industrial processes are still the major concern; this is in agreement with the findings in each city. Commercial sites have a larger increase than residential sites because they are usually closer to the industrial areas.

CONCLUSIONS

Traditional sources have received the greatest attention from control programs to date and significant reductions in emissions from these sources have resulted due to regulations both before and after the requirements for State Implementation Plans. Much of the reduction in the areawide problem has come about because of switching to cleaner fuels such as gas and distillate oil over the past couple of decades. While more could still be done with respect to fuel combustion where cleaner fuels are available, control programs under SIP's have primarily directed attention at industries, power generation, and solid waste disposal.

With respect to the three major categories of traditional sources - fuel combustion, industrial processes, and solid waste disposal - the relative contributions very significantly with the nature of the different urban areas. The fuel combustion contribution to inventoried emissions ranges from less than 20 percent in clean-fuel, industrialized areas to well over 90 percent in totally nonindustrial areas, with industrial processes accounting for most of the balance. Solid waste disposal emissions are generally less than 5 percent.

Traditional sources are still a major concern in many areas. Significant reductions in TSP levels can occur in these areas through traditional source control. This potential for reduction has been well demonstrated in several of the study cities which have undertaken to control traditional sources and equally well demonstrated by the lack of success in those cities which have not undertaken such programs.

Not only are more stringent controls warranted in many cities, but significant reductions in emissions can be expected simply from the improvement of surveillance, compliance, and enforcement programs. Generally, further control of traditional source emissions can be expected to be appropriate if the traditional source emission density is over 200 tons/year/square mile. When the density falls much below this value, control programs for other sources may be necessary. As was shown in the review of the 14 study cities, even cities with very few traditional sources in their inventories cannot be expected to bring citywide TSP levels down below 60 $\mu g/m^3$, the secondary annual standard, through traditional source control. In addition, most cities have at least one site violating the primary annual standard of 75 $\mu g/m^3$.

Though the reductions in TSP concentrations that can be expected under traditional source control vary widely with the meteorology, monitor siting, and industry type, if one starts with a poorly controlled, heavily industrialized area, the concentrations in residential, commercial, and industrial neighborhoods can be expected to decrease about 10, 20, and 25 to 30 $\mu g/m^3$, respectively, under moderately stringent controls. However, to provide an additional 5 to 10 $\mu g/m^3$ reduction in all neighborhoods would require very stringent controls. Control of fugitive emissions can reduce TSP levels 25 $\mu g/m^3$ at individual monitors.

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APPENDIX E

ASSESSMENT OF PARTICULATES FROM NONTRADITIONAL SOURCES

Even in cities where TSP emissions from traditional sources are relatively minor, citywide averages are 30 to 40 $\mu g/m^3$ above the nonurban levels, and the secondary annual standard is being violated. Monitors in apparently clean areas of a city or in smaller, nonindustrial cities have measured high TSP concentrations which cannot be explained by complex modeling or which fail to decrease as expected under controls of the State Implementation Plans. These findings indicate that a certain level of particulate is being caused by those sources not traditionally considered in air pollution control strategies. These activities are here collectively designated "nontraditional" sources.

Nontraditional sources of particulates may be divided into two categories. One category consists of obvious, distinct sources of emissions; these include construction and demolition activities, particulate emissions from tailpipes, and tire wear. The other category refers to the more general problem of natural and man-induced disruption of particles on the ground or surfaces in an urban area so that particulates can become entrained or reentrained. These two categories, specific sources and reentrainment particulates, form the framework for this Appendix.

Before the discussion of these categories, two terms merit differentiation: fugitive emissions and fugitive dust emissions. Fugitive emissions include those particulate (and gaseous) emissions that result from industrial related operations and which escape to the atmosphere through windows, doors, vents, etc., but not through a primary exhaust system, such as a stack, flue, or control system. Fugitive emissions may result from metallurgical furnace operations, materials handling, transfer and storage operations, and other industrial processes where emissions escape to the atmosphere. As they are part of the total emissions from industrial operations, they are discussed under traditional sources in Appendix D. Fugitive dust emissions, on the other hand, are generally related to natural or man-associated dusts (particulate only) that become airborne due to the forces of wind, man's activity, or both. Fugitive dust emissions may include windblown particulate matter from paved and unpaved roads, tilled farm lands, exposed surface areas at construction sites, etc. Natural dusts that become airborne during dust storms are also included as fugitive dusts. In all, over a dozen sources of fugitive dust emissions due to man's activities have been studied. These include paved roads; sand on paved roads; unpaved road; unpaved parking lots; residential, industrial, and commercial construction; highway construction; agriculture (tilling); land development; cattle feedlots; off-road recreational vehicles; unpaved airstrips; quarrying, mining, and tailings; and aggregate storage.

Since the problem of attainment of standards is most prominent in urban areas, this appendix focuses upon those fugitive dust emissions that occur in the urban environment. Fugitive dust in rural areas that results from man's activities or natural causes is discussed primarily under Large Scale Considerations in Section III.

URBAN REENTRAINMENT*

The category of nontraditional sources that has received the most attention recently is that of reentrainment, especially in urban areas. These sources have generally been ignored both in emission inventories and regulatory programs; controls for such sources are harder to implement and often outside the purview of the air pollution control agency. Because the actual reentrainment of particles is difficult to control, one approach to controlling the impact of reentrained particulate matter is to reduce the particles available. Therefore, it is important to understand where and how these particles accumulate on the surfaces in the city. The sources of particulates are discussed briefly below prior to the analyses of natural and man-induced reentrainment.

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*The commonly used term 'resuspended' is considered inappropriate because of possible confusion with the standards referring to total suspended particulates and the difficulty of distinguishing a resuspended from a suspended particulate. In addition, all particles which become entrained may not remain suspended. While the term 'reentrainment' may pose similar problems in distinguishing the entrained from reentrained particulates, it may be assumed that most particulates on the surfaces of the city were once airborne for a short time as in sanding operations.

Sources of Particulates for Reentrainment

The most widespread source of particulates for reentrainment in an urban area is the fallout and deposition of particles that occur continually in both the natural and urban environment. While there is no exact relationship between ambient TSP concentrations and dustfall rates, there is a direct correlation between these two parameters such that higher dustfall rates are observed in areas with higher TSP concentrations. In a study of 77 midwestern U.S. cities,[1] dustfall was measured over a 4-month period in different types of neighborhoods. The results indicated increasing dustfall rates as the level of activity in the area increased:

Neighborhood	Rate of total dustfall g/m^2/month
Residential	3.16
Commercial	5.45
Industrial	7.07

As the majority of the cities in this survey were small, with no appreciable industry, these dustfall rates may be considered low for larger, industrial areas. For instance, in a report on reentrained dust in Chicago, the dustfall rate was determined to be 7 to 14 g/m^2/month.[2]

Two additional comments need to be made regarding dustfall measurements. First, dustfall levels are generally measured by capturing all particulates which fall into a collection apparatus whether by natural sedimentation or induced by rainout and washout. Since rainfall in any large amounts tends to help wash particulates off of surfaces and, in an urban setting, down sewers, the actual accumulation of particulates on a surface will not be continuously rising. Rather, given a constant sedimentation rate, the loading intensity as a function of time would be similar to that in Figure E-1.

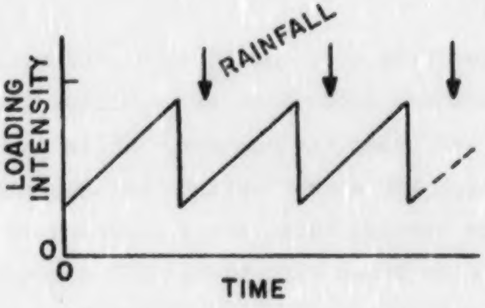

Figure E-1. Accumulation of contaminants — hypothetical case (linear buildup with rainfall)

The other comment on dustfall relates to where the measurements are made. Generally, dustfall is measured far enough above ground level so that any activities at or near the ground will not influence the measurements; typical dustfall monitors are at rooftop level. Therefore, low level emissions and activities which act to deposit particulates on surfaces such as streets, are not represented in the dustfall rates. Vehicular emissions of particulates from tailpipes and tire wear, dirt and mud carryout from unpaved parking lots and roads, spillage from trucks, and sanding operations are a few of the activities which would tend to cause higher amounts of particulates on streets than at rooftop level. These contributions to particulates are summarized below.

- Emissions from vehicles — Emissions of particulates from motor vehicles are usually calculated using AP-42[3] emission factors. Depending upon the type of vehicle, the emission rate varies from 0.33 g/km (0.21 from exhaust, 0.12 from tire wear) for light-duty, gasoline-powered vehicles to 0.75 g/km for heavy-duty, diesel-powered vehicles. As discussed later under Specific Urban Sources, about three-fourths of the tailpipe emissions and less than 10 percent of tire wear stay suspended; the remainder presumably settles on the street or bordering.

- Dirt and mud carryout from unpaved parking lots and roads - This is extremely dependent upon the number and use of such areas in a city, precipitation, and other factors. While it is not possible to provide average citywide factors for deposition from carryout, an understanding of the possible magnitude in an area with numerous unpaved areas may be obtained from a study done in the industrial Duwamish Valley of Seattle.[4] This study stated that a car driven 7.5 miles at 10 mph on a wet gravel road would gain approximately 80 pounds of mud and that an average of 0.74 pound per vehicle was carried out from dirt parking lots, based upon brushings from the tires.

- Spillage from trucks — This is similarly difficult to estimate on an average citywide basis. Spillage will be most prominent in industrial areas and around construction sites where materials are likely to be transported. Spillage was shown to be the predominant reason for nonattainment of the primary annual standard in Miami at one site.

- Sand and salt for snow control — Levels of sand and salt added to the road will depend upon meteorological conditions and approach to snow control (plowing versus salting) among cities and, within each city, the importance of keeping certain roads open. In Denver a little less than 16,000 tons of sand were added to the roads in the county (area = 77 mi^2) in 1974.

The resulting accumulation of particles on streets will be affected by removal mechanisms such as rainfall and street sweeping. A long-range loading intensity graph could be represented by Figure E-2. It is interesting to note the similarity between the buildup of particulates on roads and the increase in TSP levels alter rainfall (Figures F-5, F-7, and F-10); however, insufficient data was available to indicate any cause-effect relationship.

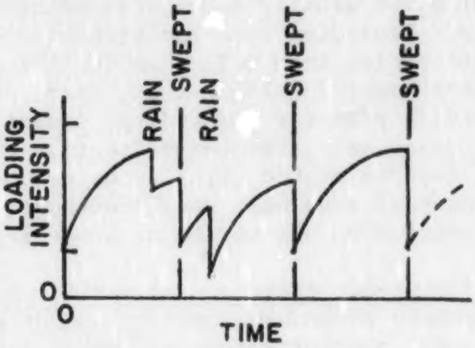

Figure E-2. Accumulation of contaminants — typical case (natural buildup with periodic sweeping and intermittent rainfall)

As may be expected, the particulate loadings on the streets due to these mechanisms vary widely with the type of neighborhood. The loadings should be much lower in a residential neighborhood than in an industrial area where materials handling is prominent, fallout from the ambient air is heavy, and unpaved parking lots and roads may be prevalent. In a light commercial area, especially in the center city where street sweeping is frequent, the total loading may be small. Figure E-3 presents these findings from a water pollution study concerning urban runoff.[5]

Natural Reentrainment

Erosion and entrainment of particulates from the soil have been extensively investigated[6-9] by agricultural scientists because wind erosion has an obvious major impact on crop fields. One of the best known examples of this impact is the "dust bowl" situation in the late 1930's when the Great Plains were severely affected by a combination of drought, high temperatures, and periodic high wind velocities. According to a study of Great Plains' duststorms in the 1950's, the average duststorm, lasting 6.6 hours, had a median TSP concentration of 4.85 mg/m^3.[10]

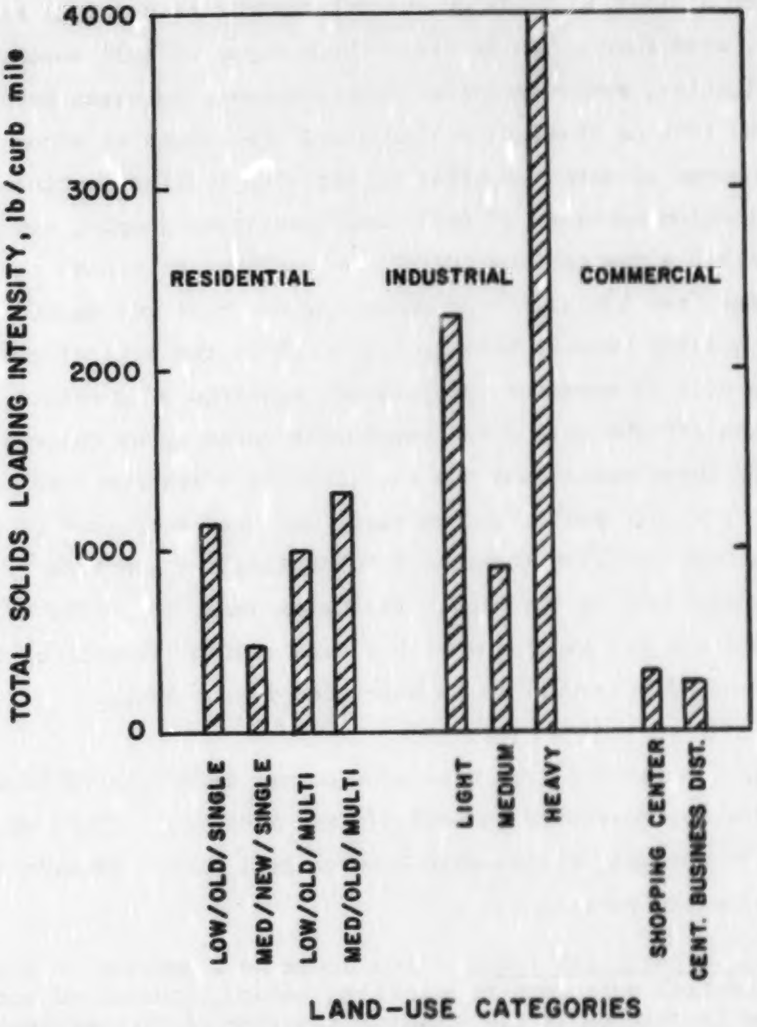

Figure E-3. Total solids loading on street surfaces – variation with land use[5]

While this discussion is primarily limited to the reentrainment of particulates in an urban environment, the mechanics and physics of soil erosion are similar to those of reentrainment from a smooth surface. Basically, wind forces can initiate three types of soil movement - surface creep, saltation, and suspension. Surface creep involves particles of the size 500 to 1000 μm that are rolled along the ground by strong winds and by the exchange of momentum after impact with smaller particles in saltation. Saltation consists of individual particles jumping and bouncing usually within a few centimeters of the surface; particles that saltate vary in size from 100 to 500 μm depending on shape and density, and are therefore quickly brought back to the earth by the pull of gravity. The third type of soil movement, suspension, consists of particles below 100 μm being lifted off the ground and completely borne up by the wind. The differences in these mechanisms and the particle sizes involved are especially important in an air pollution context. The wind will support particles as long as their falling (terminal) velocities are overcome by the upward vertical velocities of the wind. Particles under 10 μm can be suspended almost indefinitely; particles with a mass median diameter of less than 5 μm are generally assumed to be deposited in the lungs.

Fugitive dust emissions from wind erosion may be estimated from the wind erosion equation developed by Woodruff and Siddoway.[9] This equation expresses a functional relationship between soil "loss" (tons/acre/year) and the following variables:

- Soil erodibility index — This index is a measure of the potential soil loss from a bare, smooth, noncrusted surface and is related to the erodible fraction of the particular soil (fraction of the soil below 0.8 mm particle size).
- Soil ridge roughness — This parameter is an estimate of the amplitude of soil ridges or undulations.
- Local climatic factor — This factor is a function of average wind speed and soil moisture conditions. The emission rate's dependence on the cube of the wind speed is an important consideration in the analysis of worst day particulate loading.

- Length of the area subject to erosion — This length, measured along the wind direction, is a necessary parameter since some distance is required before the soil flow can reach its theoretical maximum value.
- Equivalent quantity of vegetative cover — This parameter is really a function of three other indices which measure the quantity, kind, and orientation of the vegetative cover.

Although the soil erosion equation was developed basically for agricultural areas, reasonable estimates of dust emissions from any exposed ground surface (dirt roads, desert areas) could be made with an appropriate choice of source parameters. One approximation which can be made is that the relative mass of soil loss through saltation and suspension processes is equal to the ratio by weight of the suspendible size fraction of particles to the fraction greater than 10 μm. A calculation of the wind necessary for suspension of particulates in an urban setting (Chicago), taking into account the surface roughness and the log-wind profile near the ground, indicated that a velocity of about 16 mph, measured at a height of 22.5 feet, would be the critical point.[2] Above this speed, suspension is very likely if the dust is sufficiently dry and includes particles both in the size range 100 to 500 μm and below 100 μm. A recent study[8] has revealed that aerosol derived from the soil has a size distribution which follows the size distribution of the soil itself for a range of particle radii between 1 and 10 μm, so that ample particles would be available for resuspension.

Similar analyses were conducted during this study and are presented in Appendix F of this report. The results indicate that winds above 10 to 12 miles per hour are likely to be contributing to the TSP levels. Above this speed, the reentrained dust maintains the TSP level above what would be projected based upon the dilution effect of the ventilation accompanying the wind. Therefore, the overall impact of wind neither increases nor decreases the daily TSP levels. However, cleaner surfaces (determined by comparisons after rainfall) did allow the dilution effect to reduce levels further than when the wind was blowing over dirtier surfaces (measured on days before which there was no rainfall).

In an urban area, highest winds and turbulence are often experienced in street canyons where the greatest among of particulates and larger particles are also found. Therefore, the problem of natural reentrainment must consider the vortex circulation developed in these areas. At the same time, however, the surface roughness of the urban area itself can greatly reduce the wind speeds from those measured at an outlying station. A discussion of the various conditions of wind flow perpendicular or parallel to the street canyons, under light or strong wind regimes, and their impacts, are beyond the scope of this study. Further analysis and model development are expected in a major study to be performed for EPA in Philadelphia.[11]

Vehicle-induced Reentrainment

As a measure of man's general activity in an urban area, probably no activity is so important to reentrainment as that of motor vehicles. Not only does the level of traffic reflect the total activity in an area, but it also represents the greatest general disruption of the surface dust. Much as the natural saltation process of particle movement may induce smaller dusts to become entrained in the passing air, man's activities on settled dust or dirt and sand deposited on roadways can disperse particulates into the ambient air. The wheels of the vehicles grind up the larger, nonsuspendible particles into smaller ones, break up the cohesive bonds of the dust, and impart kinetic energy to particles.

Vehicular Traffic on Paved Roads — In several studies which have used microscopy to identify the particles collected at monitors near street levels, the contribution of vehicular traffic to the TSP concentrations has been estimated to be as high as 90 percent.[12,13] However, the conclusions of these studies have several problems in their derivation. First, the microscopic analysis indicated that many of the particles being analyzed were greater than 50 μm in diameter and as high as 160 μm. As discussed earlier, such particles are not really suspendible and their measurement is most likely a result of the height of the monitor being used (~ 10 feet). Second, the analyses did not attempt to compensate for any incoming particulate from nonurban areas or any industrial contributions. Rather, all mineral products (quartz, limestone, olivine, feldspars) were directly attributed to the grinding and entrainment of the asphalt pavement. In addition to these problems in the interpretation of results, microscopic analysis is subject to the interpretation of the microscopists and cannot be considered an exact science, as discussed in Volume II.

The calculation of total emissions from paved roads, as was done in the Colorado report for developing particulate attainment strategies,[14] is based primarily upon a study of emissions from dusty paved roads in the Duwamish Valley of Seattle, Washington.[4] The emission rate developed in this study was determined by isokinetically sampling the air 8 feet behind a moving vehicle at a height of approximately 4 feet. A total of four tests were run, three on a dusty paved road with no curb and one on a paved road that was cleaned fairly frequently (see Table E-1). The results of these few tests indicated that significant differences can exist between dusty and clean streets. In both cases, the majority of the emissions were particles greater than 10 μm in size.

Table E-1. EMISSION FACTORS FOR TRAFFIC DUST FROM PAVED ROADS[4]

Speed mph	Type of road and test site	Particulate, lb/VM[a]			Percent below 10 μm	Number of tests
		Total	Below 10 μm	Below 2 μm		
20	Dusty paved roads - no curbs	0.83	0.17	0.022	20.3	3
20	Paved roads with curbs - flushed weekly - swept biweekly	0.14	0.0055		3.82	1

[a] VM = vehicle mile

In the Colorado study, the emission factor of 0.17 lb/VM was used to calculate the total tonnage of particulates that may be expected to be emitted due to traffic on paved roads that had been sanded. An analysis of the results of that study are given in the individual report on Denver (Volume III in this report series); the major conclusion is that the total tonnage determined to be emissions was much greater than the data would actually support if such levels were considered to be suspended for any length of time. The major reason for this conclusion was that over 35 percent of the sand placed on the roads would have had to be suspended to have such a high level of particulate emissions (5,800 tons) directly attributed to sanding operations.

An analysis of the impact of both natural and vehicle reentrainment that attempted to integrate the physics of reentrainment with observed values was conducted in Chicago by Abel.[2] Using over 8 years of data, this study concluded that the total amount of particulates which become reentrained and suspended is approximately 18 to 20 $\mu g/m^3$ on an average annual basis in Chicago. Vehicular traffic was responsible for three-fourths of this level and winds reentrained the other 5 $\mu g/m^3$. This value was determined to be reasonably constant from year to year, not a given percentage of the total TSP value, because the reentrainment is a function of the traffic volume, precipitation, and frequency of high wind velocities. Analyses similar to the one in Abel's thesis were conducted in the course of this study and are discussed in Appendix F.

The actual transport of particles from an asphalt road caused by car and truck traffic has been investigated by using zinc sulfide (ZnS) tracer particles which were initially less than 25 μm in diameter.[15] General findings from that experiment indicated that the fraction of tracer reentrained per vehicle ranged from 10^{-5} at 5 mph to 10^{-2} at 50 mph, and 20 to 30 percent of the material reentrained was found to be redeposited within 30 feet of the road. The results of an analysis of the exposure to reentrained ZnS at different heights are of particular interest to this study because of their implications for monitoring of ambient air quality.

Exposure, in units of mass/area, is the integrated product of particle concentration, air speed, and sampling time. Typical exposures are shown in Figure E-4 as a function of height and distance from the road. Exposure is seen to decrease with both height and distance, decreasing rapidly with increasing height over 8 feet. The results tend to support the findings of this study, which also found decreasing concentration with increasing distance from the road.

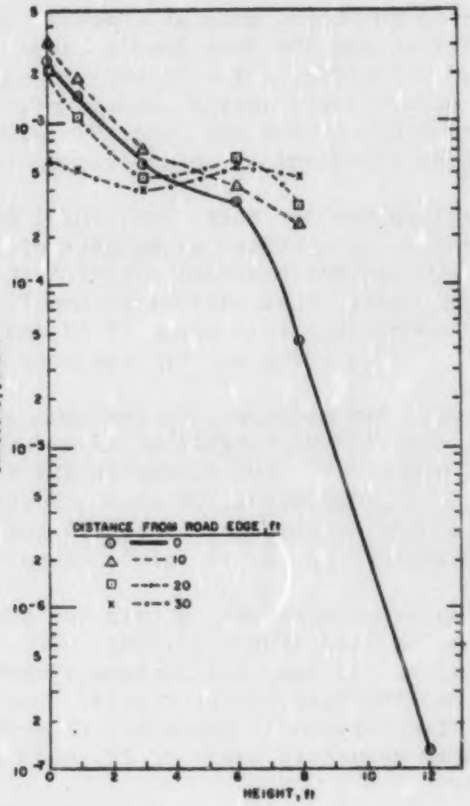

Figure E-4. Airborne exposure profiles (truck driven through at 15 miles h^{-1}, 4-day weathering, 6.9 miles h^{-1} average windspeed at 4.9 ft height)[15]

The data gathered in the course of the city case studies provided several opportunities for estimating the impact of vehicular-induced reentrainment by comparing comparable monitoring sites. The best data were the result of special studies that had been or were being conducted by the local agencies to determine for themselves the impact of traffic on the measured TSP levels. Generally this was done by monitoring in one location but at either different heights or different distances from the road, or both. The analyses of these data are given in the individual city reports; the findings are listed below.

- In Seattle two monitors, both at a height of 15 feet, were operated 25 feet and 300 feet from a heavily traveled road (average daily traffic, ADT = 13,000) in an industrial/commercial area. Forty sets of paired measurements were made between October 1974 and June 1975 with geometric mean concentrations of 89 and 55 $\mu g/m^3$, respectively.
- In San Francisco two monitors, both about 40 feet back from the road, were operated at heights of 15 feet and 93 feet in the central business district (CBD). One hundred eight paired observations in the first 8 months of 1971 indicated geometric means of 47 and 42 $\mu g/m^3$, respectively. (The lower monitor had poor ventilation.)
- In Philadelphia two monitors, in the same quadrant of the block, were operated at heights of 13 and 60 feet in a heavily traveled area in the CBD (areawide ADT = 105,000; however, nearest roads = 2,900 and 7,700 ADT). Forty paired observations were made between November 1974 and June 1975 with geometric means of 110 and 83 $\mu g/m^3$, respectively.
- In Philadelphia two monitors, within two blocks on a heavily traveled road (ADT = 30,000), were operated at heights of 13 and 35 feet and distances back from the road of 35 and 100 feet, respectively. Twelve pairs of concurrent observations in September through December 1974 indicated geometric means of 115 and 65 $\mu g/m^3$, respectively.

While these data are in agreement with the experimental results discussed previously in terms of showing a decreasing impact from traffic with distance, they are not sufficiently detailed in any instance to provide more than a linear relationship between two points. Similarly, the differences between the various monitor settings, especially the degree of impact of traditional sources, varied considerably so that comparisons between different sets of paired observations were difficult.

In an attempt to bypass some of these problems and develop a quantitative relationship between the traffic activity and measured TSP levels, available traffic and TSP data were analyzed for Miami and Providence, two areas which were believed to be not influenced by industry. Where possible in each city, average daily traffic (ADT) levels were obtained for monitors that were potentially influenced by traffic. Initial comparisons between ADT and TSP levels without considering the monitoring site did not produce any good relationships. However, when the distance of the monitor from the traffic was taken into account by calculating the slant distance $\left(SD = \sqrt{(\text{height})^2 + (\text{distance})^2}\right)$, a comparison of the ADT/SD to the TSP concentration implied that a linear relationship could be assumed to exist with good correlation. The result of this analysis is plotted in Figure E-5 along with the relationship derived and correlation coefficients. The constant value of 46 in the Providence relationship and 44 in the one for Miami can be interpreted as representing the nontraffic-related contribution to the citywide average TSP; i.e., if $ADT = 0$ or $SD \to \infty$.

Because of the lack of a constant, citywide value for a nontraffic-related contribution in cities with a larger industrial base, comparable analyses in such cities failed to provide similar results. In other nonindustrial cities (Washington and Oklahoma City), construction activity was prominent and hindered the isolation of the effect of traffic activity on measured TSP levels.

The form of the relationships derived for Miami and Providence was considered to be in accord with the experimental results presented in the literature; i.e., TSP concentration decreasing with slant distance. Several attempts were made to find better correlation using the data from these two studies. Various weighting factors for the height of

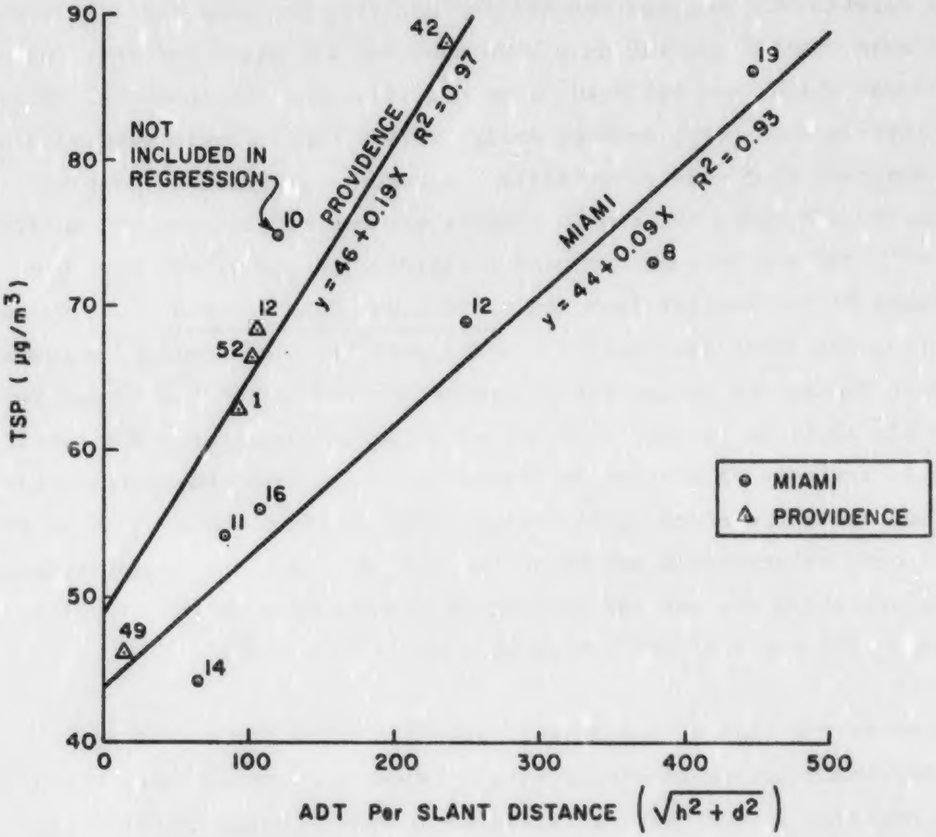

Figure E-5. Providence/Miami comparison of ADT per slant distance versus TSP (nearest major street) the monitor and its distance back from the road failed to provide any increase in the correlation; attempts to derive exponential relationships were similarly unsuccessful. The form of the relationships presented was thus assumed to be the most appropriate one for the data being used.

The difference in the two slopes is believed to reflect the difference in monitor placement in the two cities. In Providence, where the slant distances varied more because of changes in height, the relationship indicates that the TSP level due to motor vehicles changes faster with an equivalent change in ADT/SD than in Miami; Miami's monitors were almost consistently placed at the same height but the distance back from the road varied greatly. Such an effect is expected based on the literature discussed previously.

Under the assumption that the variation in TSP with ADT/SD was a valid relationship, similar relationships were investigated for the two-point data sets found in the city studies. In Seattle, where the terrain was fairly open and the only difference in the monitors was their distances back from the road, the slope of the line was found to be 0.07 ($\Delta TSP = 0.07 \times \Delta \frac{ADT}{SD}$). In Philadelphia, for the two sites on the heavily traveled road and where the difference in slant distance had a major component from both height and distance back from the road variations, the slope was approximately 0.10. These findings appear to confirm that the change in height has a slightly greater effect than the change in distance. A specific relationship that addresses these variations is expected to result from a current study of reentrained dust in Philadelphia.[11]

The overall impact of vehicular activity on citywide TSP levels and the attainment of the standards can only be estimated from these findings. As suggested earlier, the constant values in the Miami and Providence relationships can be considered representative of the citywide TSP values without the influence of traffic. Therefore, the difference between those constants and the actual citywide values would be the citywide TSP contribution from reentrainment dust. In Miami, the citywide TSP level in 1974 was 62 $\mu g/m^3$ so the reentrained contribution would have been 18 $\mu g/m^3$; in Providence, the citywide TSP level of 61 indicates a 15 $\mu g/m^3$ contribution from reentrainment on the citywide level.

In conclusion, reentrained particulates from traffic on paved roads can have a major impact on the citywide TSP levels. At individual monitors the actual impact varies with the horizontal and vertical distance from the road as well as with the amount of traffic on the road. From the data analyzed in two cities and two special cases, the vehicle-related TSP may be as high as 50 $\mu g/m^3$ on an average basis for monitors close to heavily traveled roads. For shorter time periods with different meteorological and traffic conditions, this value may vary widely. If many of the monitors in a city are located close to streets, there would be a significant impact on the measured citywide TSP levels.

The above analysis basically addresses the question of impact of traffic on measured particulate levels with no distinction between reentrained particulates and emissions from tailpipes or tire wear. However, the later discussion of these sources indicates that the majority of the vehicular contribution at monitors close to the road is from reentrained particulates. For instance, even if the emission factor of particulates under 10 μm from a clean road (as given by Roberts[4]) is used, each car would be reentraining 2.5 grams/mile as opposed to emitting 0.31 grams/mile from tailpipes. Therefore, at least 85 percent of the particulate matter originally suspended due to vehicles results from reentrained particles.

Vehicular Activity on Unpaved Areas - In many urban areas dirt or gravel roads and parking lots are used by individual establishments or in industrial areas because of the expense of adequate paving. As discussed previously, these areas can be sources of dirt for carryout to paved areas and may also serve as areas for naturally reentrained dust. In addition, vehicular activity on these areas can cause particle reentrainment.

One of the major sources of concern in Roberts' thesis[4] was gravel roads. Isokinetic sampling with the same equipment as used on paved roads provided estimates of the emissions from dry gravel roads at different speeds. These tests signified that emissions increased exponentially with speed and the percentage of particulates below 10 μm also increased with speed so that almost 16 times as much particulate below 10 μm was determined to be emitted at 30 miles per hour as at 10 miles per hour.

The emission factors developed from Robert's work are given in Table E-2. Almost 10 times as much particulate was found to be emitted from gravel roads than from a dusty paved road on a per vehicle mile basis at the same speed. This would imply a greater loading from gravel roads than from paved roads; however, the ADT on gravel roads would probably be more than on order of magnitude less than on paved roads. Therefore, the contributions to local TSP levels from gravel roads may be expected to be comparable to those of paved roads. Since gravel roads are much less widespread in an urban setting, the impact on city-wide TSP concentrations may be considered minimal.

Table E-2. EMISSION FACTORS FOR TRAFFIC DUST FROM GRAVEL ROADS[4]

Speed, mph	Test site	lb/VM total particulate	lb/VM below 10 microns	lb/VM below 2 microns	Percent below 10 microns	Number of tests
10	Gravel road No. 1	3.5	0.58	0.10	16.7	1
20	Gravel road No. 1	7.0	1.9	0.24	27.4	17
30	Gravel road No. 1	22.2	9.0	0.77	40.4	1
20	Gravel road No. 2	7.3	2.0		27.1	1

Other estimates of emissions from unpaved roads have been made by measuring ambient and deposited particulates. In one study,[16] the emission factor was determined to be 1.94 lb/vehicle-mile at 30 mph for dirt roads. Taking into account the silt content for roads (gravel road silt content ~ 12 percent), another sampling study[17] developed the following equation to express the emission factor for particles smaller than 100 μm:

$$e = 0.81(s)(S/30)$$

where e = emission factor (pounds per vehicle-mile)
s = silt content of road surface (percent)
S = average vehicle speed (miles per hour)

Taking into account the number of dry days per year, another study[18] determined the following emission factor for particles smaller than 30 μm (the assumed cutoff point for a hi-vol sampler):

$$e = 0.49\ s\left(\frac{S}{30}\right)\left(\frac{d}{365}\right)$$

where d = the number of dry days per year.

This latter factor was used in developing a national emission inventory for fugitive dust which included unpaved roads, unpaved airstrips, construction and agricultural tilling. (Due to the widespread nature of the study, many assumptions were made to allocate these emissions in each county.) A comparison of emissions from unpaved roads with those from traditional sources is given in Table E-3 for those central counties analyzed in the course of this study. The data in this table imply that the unpaved road emissions in counties that are not totally urbanized can be 10 to over 30 times the emissions from traditional sources. Even in urbanized areas, where unpaved roads are not common, the fugitive dust from unpaved roads may be over 10 percent of the traditional emissions in the county.

Based on the analyses conducted above, which indicate that the impact of fugitive dust from vehicular activity decreases quickly with distance, these numbers are believed to be inappropriate for direct use in air quality planning. If these fugitive dust emissions were treated the same as traditional emissions and used in rollback calculations, excessive, undeserved emphasis would be placed on these sources at the expense of control of traditional sources. While these amounts of particulate may be temporarily reentrained due to vehicular activity, they are not suspended for any length of time. If they were, the rural areas of counties would be expected to have TSP levels as high as those found in the cities; such is obviously not the case. Therefore, the use, if any, of these numbers would have to be limited to inputs to models that adequately reflect the deposition and other removal of the particulates.

Control Approaches

The above discussions illustrate that a significant contribution to the measured TSP levels in a city can result from reentrained particulates, but that the degree to which the impact is measured is highly dependent on the siting of the monitors. The reentrained contribution is mostly

Table E-3. COMPARISON OF FUGITIVE DUST EMISSIONS FROM UNPAVED ROADS WITH TRADITIONAL SOURCE EMISSIONS IN MAJOR COUNTIES OF 14 AQCR'S

AQCR	Major county	Emissions from unpaved roads, tons per year	Emissions from traditional sources, tons per year	Ratio
Baltimore	Baltimore City[a]	510	7,000	0.07
Birmingham	Jefferson	193,000	110,000	1.75
Chattanooga	Hamilton	N.A.	10,300	—
Cincinnati	Hamilton	76,990	56,100	1.37
Cleveland	Cuyahoga[a]	18,800	210,000	0.09
Denver	Denver[a]	1,270	9,700	0.13
Miami	Dade	70,940	8,000	8.88
Oklahoma City	Oklahoma	85,920	2,600	33.55
Philadelphia	Philadelphia[a]	2,660	31,600	0.08
Providence	Providence	139,830	7,800	17.88
San Francisco	San Francisco[a]	660	4,800	0.14
Seattle	King	197,770	7,300	27.17
St. Louis	St. Louis City[a]	1,220[b]	15,600	0.08
Washington, D.C.	District of Columbia[a]	100	5,600	0.02

[a] These counties are almost totally urbanized so the travel on unpaved roads is expected to be minimal.

[b] This represents the emissions from St. Louis County, a much larger, less urbanized area; actual reported emissions for St. Louis City were 159,900 tons/year suggesting a coding error confusion with the county.

man-induced, and the majority of this in an urban area is from vehicular traffic on paved roads. It is, therefore, this latter area that should receive greatest attention in any formulation of a control strategy.

Under current EPA regulations and guidance, two basic approaches are possible. The great diversity of monitor siting allowed in various cities has already resulted in either highlighting or concealing the problem of reentrainment. In the 14 cities studied under this contract, the mean monitoring height varied from 10 feet (3 meters) in Birmingham to 56 feet (17 meters) in Providence; distances back from the road varied even more. Since current EPA guidelines[19] allow hi-vols to be placed from 2 to 15 meters above ground and no guidelines are set for the distance back from a road, reductions of 50 $\mu g/m^3$ or more may be reasonable in areas of high traffic flow simply by relocating samplers as witnessed at the two sites on South Broad in Philadelphia. Therefore, the problem of monitor siting guidance is the first one that needs to be resolved; this issue is discussed further under Monitoring Considerations in Section III.

Once the monitor location is set and the TSP concentration due to traffic on paved roads still provides an important contribution to the level of TSP measured, control methods applicable to vehicular activity must be considered. Since reduction of ADT is an extremely difficult task and has seen only small success as a control method for CO, hydrocarbons, and other traditional automobile-related pollutants, such a measure is not discussed below. Rather, those measures which act to prevent the deposition of particles for reentrainment or serve to remove such particles are given primary consideration.

Deposition Control — A viable approach to controlling reentrained particulates is to reduce the amount of particulates available for reentrainment; such measures are also beneficial for water pollution control. The feasibility of this type of control varies with the source of the particulate:

Fallout – This contribution to the total particulate loading on the streets is small and no direct control is appropriate. The fallout level will decrease automatically with control of traditional source emissions and the reduction of lead in gasoline.

Carryout – In areas where dirt and mud carryout from unpaved roads and parking lots is found to contribute significantly to the loading of dust on paved roads, requirements for paving or stabilization of the unpaved areas would be warranted.

Spillage – The additional loading on streets due to spillage from trucks may be easily regulated against; however, enforcement may be a problem. Further study on this matter is needed but it is probably possible to require specific equipment on trucks to prevent spillage.

Sanding – Because the short-term hazard of slippery roads is more prominent than the hazard due to reentrained dust, sanding and salting operations will obviously continue. Analysis of the efficiency of sanding may result in procedures that apply less sand more effectively; however, on-the-road implementation of such procedures is difficult. (Systematic road cleaning after sanding operations would be more appropriate.)

Street Cleaning – Since preventing all deposition of particles on a paved surface is not possible, an alternative or auxiliary approach to control of particle reentrainment is to remove the particles from the surface. As part of a water pollution study,[5] street cleaning practices throughout the nation were evaluated through a review of the literature, a detailed survey of current practices in several sample cities, and several controlled tests. This study indicated that present methods of cleaning streets fall into two categories of machines – street sweepers and street flushers.

Machine sweeping accounts for the great majority of street cleaning performed in most communities. Motorized street sweepers are designed to loosen dirt and debris from the street surface (this debris is normally most concentrated in the gutter area), transport it onto a moving conveyor and deposit it temporarily in a storage hopper; the sweeper also typically contains a dust control system. Three basic types of sweepers are in use. The most common is a rotating gutter broom that moves materials from the gutter area into the main pickup brook, which rotates to carry the material onto a belt and into the hopper. A second class of sweepers uses a regenerative air system. These sweepers are designed to "blast" the dirt and debris from the road surface into the hopper; a portion of the air is recycled and the rest of the air is vented through the dust separation system. A third type, vacuum sweepers, has been in use in Europe for many years and in limited use in this country. These vacuum sweepers use both a broom for loosening and moving street dirt debris and a vacuum system to pick up the debris. All material picked up by the vacuum nozzle is saturated with water on entry and passes into a vacuum chamber where the water-laden dust and dirt drop out of the air stream.

In the controlled tests to determine street sweeping efficiency (using only the first type of sweeper above), an overall effectiveness of 50 percent was found. However, the experiments indicated that this removal was almost entirely in the larger size particle range (greater than 100 μm) and that, below 100 μm, more particles were found after sweeping than before. In addition, the street sweeping operation, which is principally directed at removing particles along the curb, tended to redistribute the loading on the street so that more particles were located on previously cleaner areas; i.e., toward the middle of the street. These findings raise serious doubts about the use of sweepers with only brooms for air pollution purposes. Those sweepers that use air to blast the dust off the street or use a vacuum system are expected to show better efficiency at lower particle sizes, but data for a careful evaluation were not available.

Instead of, or in addition to, street sweeping, many cities will flush the street with water. A street flusher consists of a water supply tank mounted on a truck or trailer, a gasoline engine-driven pump for supplying pressure, and three or more nozzles for spreading the water as directional sprays. The large nozzles on the flusher are individually controlled and are usually placed so that one is directed across the path of the flusher and one on each side is pointed out toward the gutters. Street flushing, as presently conducted, serves only to displace dirt and debris from the street surface to the gutter. The volume of water used is insufficient to transport the accumulated litter to the nearest drain, and therefore the dust is not actually removed from the streets. Should flushing result in transport into the drain (past the catch basins), additional loading is put on the sewer system.

SPECIFIC URBAN SOURCES

In addition to reentrained dust, other sources in urban areas have not been traditionally considered major contributors to the TSP levels and therefore have received little attention in the formulation of control strategies for particulates. Yet these sources may be considered true emission sources as the particulates arise directly as a result of the individual activity rather than as a by-product. As with reentrained dust, several recent studies have suggested that these sources may be having more of an impact than previously thought. Of particular interest in a crowded urban area are the tailpipe emissions from automobiles and the emission of rubber due to tire wear. In addition, construction/demolition activities are constantly occurring in cities and may add to the total TSP levels measured. Each of these sources is discussed below.

Transportation Sources

Although particulates from the transportation sector have been inventoried, they have seldom been regulated except through ordinances prohibiting smoking vehicles and Federal restrictions on aircraft. Controls on motor vehicles have centered around emissions of carbon monoxide, nitrogen oxides, and hydrocarbons which are one to two orders of magnitude greater than emissions of particulates. In addition, particulates from the transportation sector have generally been assumed to be insignificant when compared with emissions from traditional sources. However, as emissions from traditional sources have been reduced under implementation planning, particulates from the transportation sector have become increasingly more important. To provide an idea of the relative importance of the transportation sector, Table E-4 lists the emissions from all sources categorized as transportation (including tailpipe emissions, tire wear, aircraft, off-road vehicles, vessels) in inventories for each of the major counties in the 14 AQCR's studied. When these emissions are compared with the total emissions from traditional sources, transportation emissions are shown to add a significant contribution to the total inventoried emissions. This discussion focuses on the contribution of tailpipe emissions and tire wear to the ambient TSP levels.

Tailpipe Emissions - The emission of particulates from automobile and truck tailpipes is not a source that has been ignored in the past in terms of being included in emission inventories. Emission factors published in AP-42[3] are most often used in determining emission levels; these are listed in Table E-5.

Table E-5. PARTICULATE EMISSION FACTORS FOR VEHICLES FROM AP-42[3]

Vehicle type	Fuel	Exhaust emission rate, g/mi
Light-duty	Gasoline	0.34
	Diesel	0.73
Heavy-duty	Gasoline	0.65
	Diesel	1.2

Attempts to separate out the contribution of motor vehicles to the total TSP measured have centered around the use of lead as a tracer element. On a national basis, automotive emissions of lead were calculated to be 75 percent of the total lead emissions in 1970.[20] In most urban environments where lead, copper, and zinc smelters, grey iron foundries, or

Table E-4. COMPARISON OF PARTICULATE EMISSIONS FROM TRANSPORTATION WITH TRADITIONAL SOURCE EMISSIONS IN MAJOR COUNTIES OF 14 AQCR'S

AQCR	Major county	Emissions from transportation,[b] tons per year	Emissions from traditional sources, tons per year	Ratio
Baltimore	Baltimore City	2,960	7,000	0.42
Birmingham	Jefferson	3,050	110,000	0.03
Chattanooga	Hamilton	1,420	10,300	0.14
Cincinnati	Hamilton	3,490	56,100	0.06
Cleveland	Cuyahoga	6,410	210,000	0.03
Denver	Denver	3,060	9,700	0.32
Miami	Dade	4,870	6,000	0.61
Oklahoma City	Oklahoma	1,110[a]	2,600	0.43
Philadelphia	Philadelphia	6,650	31,600	0.21
Providence	Providence	2,180	7,800	0.28
San Francisco	San Francisco	1,095	4,800	0.23
Seattle	King	5,190	7,300	0.71
St. Louis	St. Louis City	1,360	15,600	0.10
Washington, D.C.	District of Columbia	1,500	5,600	0.27

[a] Does not include 2,820 tons/year from aircraft.

[b] Includes particulate emissions from tailpipes, tire wear, aircraft, off-road vehicles, vessels.

or other major point sources of lead are not prevalent, ambient lead levels are assumed to be due almost entirely to vehicular activity. Therefore, if the ratio of the total suspendible particulate emissions from tailpipes to the suspended lead emissions is known, the ambient levels of lead can be multiplied by this ratio to provide the ambient TSP contribution due to total tailpipe emissions.

Such analyses of lead and total emissions have been conducted in several studies with values for the ratio ranging from 3 to 7.5 depending upon the model year of the car, gasoline used, and definition of suspendible particulates. Basing their calculations on these previous studies and taking into account the vehicle age distribution in the Los Angeles area, another study[21] developed the following estimates of weighted average emission factors for light-duty motor vehicles:

Total tailpipe particulates = 0.43 g/mi
Suspended tailpipe particulates = 0.31 g/mi
Total lead emissions = 0.19 g/mi
Suspended lead emissions = 0.08 g/mi

Using these data, the ratio between suspended tailpipe particulates and suspended lead would be 3.9. However, this ratio uses a vehicle age distribution specific to Los Angeles in 1972, was calculated based upon interpretation of a range of experimental data, and ignores differences between light- and heavy-duty vehicles and between gasoline versus diesel fuel which contains no lead. For different areas of the country, this ratio may thus be assumed to range from 3 to 5.

Ambient lead levels are routinely measured in major cities through analysis of NASN filters and many state and local agencies also perform their own studies for lead. (California has an air quality standard for lead of 1.50 $\mu g/m^3$ for a monthly average). One report[22] reviewed ambient lead levels contained in the National Aerometric Data Bank (NADB) and found average annual concentrations ranging from 0.5 to 2 $\mu g/m^3$ with a few cities measuring 3 to 4 μg/m^3. These lead data suggest that tailpipe emissions are contributing from 1 to 20 μg/m^3 to the total particulate levels measured.

City study findings - Similar data from the NADB were provided for the 14 cities studied under this effort. To the extent that the data were available, Table E-6 lists the average lead concentrations at the NASN site in each city for the years 1972 to 1974. These values reflect the middle range of those reported above; i.e., around 1 μg/m^3. Therefore, it may be assumed that tailpipe emissions are generally contributing 3 to 5 μg/m^3 to the ambient levels.

Table E-6. LEAD CONCENTRATIONS (μg/m^3) AT NASN SITES, 1972 TO 1974

City	1972	1973	1974
Baltimore	1.6432	0.9244	1.1533
Birmingham	1.0599	1.1581	1.1346
Chattanooga	1.2176	(0.6475)[b]	(0.6960)[b]
Cincinnati	1.5155	NA	(0.8341)[b]
Cleveland	1.2976[a]	NA	NA
Denver	1.9525[a]	(3.0351)[c]	NA
Miami	1.3148	1.5827[a]	1.0840
Oklahoma City	1.1518	(0.6343)[b]	1.0255[a]
Philadelphia	2.0144	(1.0772)[c]	1.6071
Providence	1.2391	0.8929[a]	1.0164[a]
San Francisco	1.1787	1.1607	0.9340
Seattle	1.1574	1.5176	(1.0162)[b]
St. Louis	0.9407	(0.6079)[c]	1.1845
Washington, D.C.	1.3292[a]	NA	(0.4889)[c]

[a] Average of 3 quarters' data

[b] Average of 2 quarters' data

[c] 1 quarter's data

In most of the cities where data are complete enough for comparison, the lead levels have apparently decreased 10 to 20 percent between 1972 and 1974. This decrease may be a result of increased use of lead-free gasoline and also reduced vehicular activity in response to the energy crisis. The percent decrease in TSP due to total tailpipe emissions would not necessarily be equivalent to the percent reductions in lead concentrations since the ratio of total to lead emissions will be increasing over time as new cars replace older ones. In any event, the decrease is negligible compared to the range of uncertainty in the ratio.

In addition to the NASN data, several local agencies provided to GCA results of their metals analyses at particular monitoring sites. Selected filters from these cities were analyzed for metals by EPA. The results and additional supporting data are discussed in the appropriate city reports and are summarized below; the analytical techniques used by the various agencies are presented in Volume II.

> Baltimore - The Maryland Bureau of Air Quality Control runs chemical analyses on monthly composite samples to provide monthly and yearly average levels for six stations. The annual average concentration of lead ranged from 0.82 to 1.73 $\mu g/m^3$ and monthly averages ranged from 0.36 to 3.08 $\mu g/m^3$.. In all cases the lead contribution was less than 2 percent of the total suspended particulate concentration.
>
> Miami - Annual arithmetic averages of lead concentrations at 12 Miami monitors in 1974 were provided by the Metropolitan Dade County Pollution Control Department. These values ranged from 0.6 to 2.3 $\mu g/m^3$. At the seven sites for which average daily traffic (ADT) and slant distance (SD) were known, a regression analysis indicated a positive correlation ($r^2 = 0.664$) between lead concentration and ADT/SD; however, the regression equation implied a very small change in lead concentration with large changes in ADT/SD, The lead contribution was generally less than 2 percent of TSP.
>
> In a special study conducted by EPA for this effort, 2-hour elemental concentrations were compared with the hourly traffic counts for 1 week. These data illustrated the expected relationship of increasing lead concentration (as high as 4.6 $\mu g/m^3$ for a 2-hour average) with increasing traffic, especially in the early morning when rush-hour traffic started before mixing height and wind speed increases caused a drop in lead concentration. The average lead concentration for the week was about 0.4 $\mu g/m^3$.

Oklahoma City - Analyses of hi-vol filters by the city-county agency indicated annual average lead concentrations ranging from 0.15 μg/m^3 in a remote, rural area to 1.54 μg/m^3 in the center city-commercial area. At one site, in a location considered fairly rural, a nearby highway elevated levels to 0.66 μg/m^3. The highest monthly average reported in 1974 2.38 μg/m^3 was measured at a residential site. EPA analysis of individual filters selected by GCA provided similar results but with a wider range - 0.11 to 3.60 μg/m^3.

Philadelphia - The Philadelphia Air Management Services laboratory provided the results of metals analyses done to date on their filters. Two sites had a year of lead data. One in a dense residential area, had an annual mean of 1.19 μg/m^3 while the other site, located in an outlying, light-industrial setting, had an annual mean of 0.85 μg/m^3. The highest daily lead concentration measured at each site was 6.19 and 3.18 μg/m^3, respectively. A special 6-month study[13] conducted at four sites for the Air Management Services found average lead values of 1.30 to 2.08 μg/m^3. The lead data at the residential site in Philadelphia were reported on a daily basis with 95 percent of the days in 1974 accounted for. An analysis of the day of the week fluctuations in lead indicated that levels of lead were 40 percent lower on Sunday and 25 percent lower on Saturday than during the rest of the week. This weekly trend was consistent with the estimated changes in daily traffic.

San Francisco - Four years of complete lead data were presented in a report by the Bay Area Air Pollution Control District.[23] This report illustrated a continuing decline in the District-wide average from 1.30 μg/m^3 in 1970 to 0.78 μg/m^3 in 1973. The highest annual level in 1973 of 1.67 μg/m^3 was recorded at a site downwind from a major freeway; the lowest value of 0.35 μg/m^3 was monitored in an area subject to some industry but little traffic.

Six sets of paired filters from two sites, one in San Francisco County and the other at a site with the highest annual average due to fugitive dust, were analyzed by EPA. The results indicated that the monitor exposed to traffic was consistently measuring levels of lead more than twice those of the more rural site. In addition, while the San Francisco site averaged 2.5 percent lead, the site influenced by fugitive dust had less than 0.7 percent lead on the hi-vol filters.

Seattle - An analysis of the constituents of total suspended particulates in the industrial valley of Seattle had been conducted previously under EPA contract.[24] This study found average lead values in the valley of 1.50 to 3.94 μg/m^3 over a 5-month period. The highest level was at a site influenced not only by traffic but also by activity at a steel mill, a junkyard, and lead battery reclaiming facility. The lowest value was at the site discussed under reentrainment which was subject primarily to traffic.

St. Louis - EPA also provided 2-hour elemental concentration at two sites in St. Louis for about 1 week. Unfortunately, simultaneous traffic counts were not available so a direct correlation between traffic and lead could not be shown. Although no diurnal pattern was obvious, the lead concentrations showed the expected weekly pattern of lower values on Saturday and even lower values on Sunday.

Washington, D.C. - Daily values of lead in 1974 were reported for the NASN site by the District's Department of Environmental Services. These values ranged from 0.37 to 2.9 $\mu g/m^3$ with an annual average of 1.03 $\mu g/m^3$.

The special sampling studies conducted by EPA in Miami and St. Louis also provided data on particle sizes by elemental composition. Results in both cities indicated that the lead particles being sampled are extremely small. Only a small percentage are greater than 4 µm in diameter, and the largest percentage was collected in the last impactor stage, implying the particles had an effective aerodynamic diameter of less than 0.25 µm. This small diameter means that the lead would be dispersed and transported much as a gas with very little fallout with distance. Therefore, it may be expected to be measured at rooftop levels or even in more remote areas.

The particle size of lead can be contrasted with that of tracer elements often associated with reentrained dust - aluminum, silicon, and calcium. These elements were usually found in higher quantities at the larger size ranges (greater than 2 µm). While this size of particles is also suspendible, the transport can be expected to be lessened to some extent.

A compilation of all the sites for which some lead data were available provided 49 monitors from six cities (Baltimore, Miami, Oklahoma City, Philadelphia, San Francisco, Washington) with annual average lead concentrations as well as individual filter analyses from several sites in the other cities discussed above. Those monitors with annual data were grouped according to their site classifications and then averaged to provide a mean concentration. Because the monitoring sites had a wide range of local influences affecting the measured lead levels, Figure E-6 presents not only the mean values for each of the site classifications but also the range of values found. Since there were only four monitoring sites under the classification of rural and industrial, these averages and ranges may not be as representatitve of situations found in other cities.

By using the ratios developed earlier, these lead data can be extrapolated to a determination of the total concentration contributed by tailpipe emissions. While the actual impact will depend upon variables such as monitor siting and local traffic, the contribution from tailpipes may be assumed to be in the range of 2 to 10 $\mu g/m^3$ in industrial and commercial areas, 5 $\mu g/m^3$ or less at residential sites, and less than 2 $\mu g/m^3$ at monitors remote from any heavy traffic activity.

Control approach - In urban areas where tailpipe emissions are found to be contributing 5 to 10 $\mu g/m^3$ to the TSP loading, control of tailpipe emissions may be worthwhile. The most common suggestion for lower tailpipe emissions is to reduce or remove the lead in gasoline. Although the lead particulates were estimated above to be 26 percent of the tailpipe emissions, the removal of lead from gasoline has a synergistic relationship as other metal constituents are also reduced. It has been estimated that the combustion of lead-free gasoline produces 85 percent less particulate.[25] Since diesel fuel, accounting for 10 percent of the tailpipe emissions on a national average, has no lead in it, the requirement for all cars to burn lead-free gasoline may reduce center-city particulate concentrations around 5 $\mu g/m^3$. The current use of lead-free gas by cars with catalytic mufflers and other post-1971 cars is already accomplishing much of this strategy and should be considered in future air quality planning.

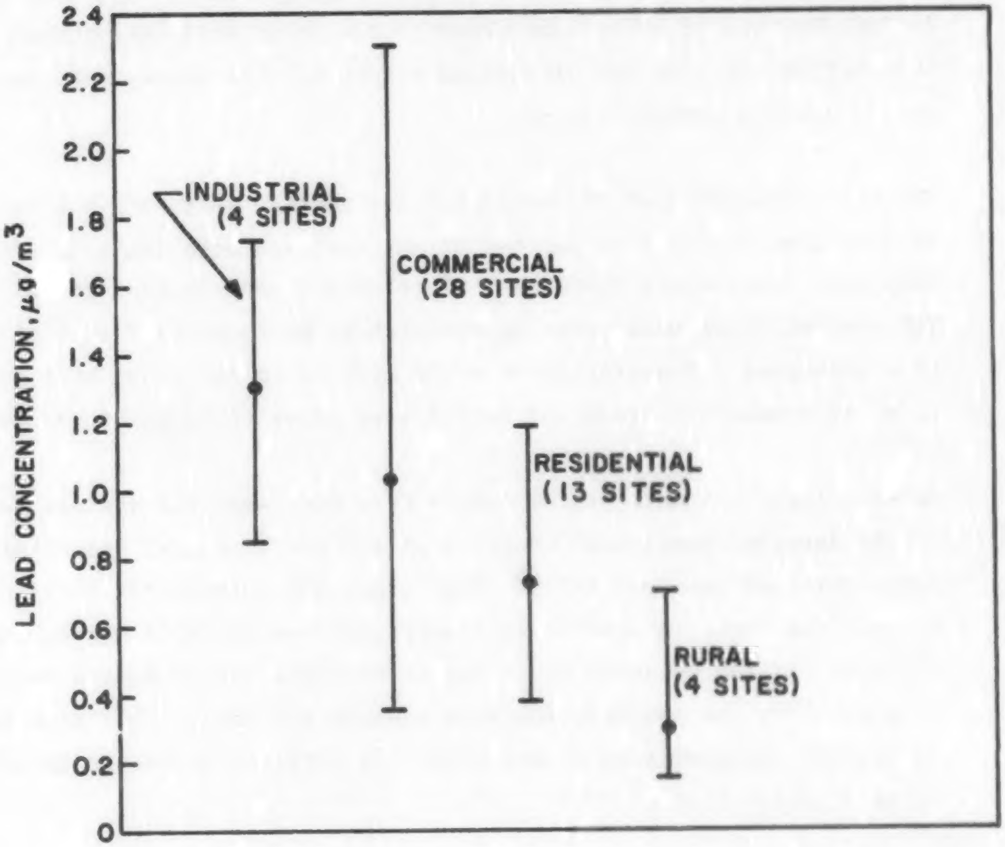

Figure E-6. The range and average of annual lead concentrations found at monitoring sites

Tire Wear - Aside from direct tailpipe emissions and reentrained dust, automobiles are known to generate particulates simply from the deterioration of the body and parts. Rust, corrosion, and friction of one part on another are all known sources. However, their magnitude is small compared with the wear that is seen on tires. In the U.S., an estimated 660,000 tons of tire-tread are worn away each year.[26] Since over half of all vehicle-miles traveled (VMT) is in urban areas, approximately 350,000 tons of rubber are added to the urban environment each year. Considering the size and widespread nature of this source, its impact on air quality warrants study.

For the calculation of TSP emissions due to tire wear, EPA has used a rate of 0.20 g/mi or about 60 percent of the tailpipe emission rate from light-duty gasoline-powered vehicles.[3] Tire wear's contribution to the total TSP concentration would thus be expected to be about half that of tailpipe emissions. Concentrations would then be on the order of 1 to 5 $\mu g/m^3$ in commercial areas and only a very minor contribution elsewhere.

An even lower estimate of the impact from tire wear was derived in a fairly detailed analytical study comparing the elemental and chemical composition of measured TSP.[26] That study determined that 5 to 10 percent of the tread material that disappears from tires in use becomes airborne and the relative contribution to total TSP is on the order of 20 percent of the contribution from vehicle exhausts. This provided an average concentration of airborne tire particulate matter in urban areas of about 1 $\mu g/m^3$.

Two separate studies by the same group of analysts have provided conflicting data on the levels of rubber tire fragments in samples collected in Philadelphia. In the earlier study,[12] the analysis of hi-vol filters implied an estimated weight percentage due to rubber tire fragments of 10 to 40 percent, amounting to 10 to 50 $\mu g/m^3$. In a follow-on study,[13] rubber tire fragments were found to represent only a minor (0.5 to 5 percent) or trace (<0.5 percent) amount of the material collected on a weight percentage basis. No explanation of these differences was given.

City study findings - Although filters were selected from each city for microscopic analysis, neither the selection of a few filters nor the accuracy of the microscopy were believed to be sufficient to characterize the cities. However, the numerous filters from among the cities were considered to be adequate for averaging contributions according to the various classifications for the monitoring sites.

By multiplying the average percentage contribution of rubber tire fragments to total visible loading (diameter >1 μm) on the hi-vol filters at each sampling site selected for analysis by the annual mean TSP for that site for 1974, and under the assumption presented in Section II that 85 percent of the loading was visible, average annual rubber loadings could be estimated for each site. These estimated loadings were then grouped according to site type and averaged; these average values, along with the range of values observed for each site type, are plotted in Figure E-7. It must be cautioned that because of the nonrandom process of filter selection, the discrepancies noted in replicate microscopic analysis, and the use of only one to six filters to characterize the site for the whole year, the values given could easily be off by several $\mu g/m^3$. However, with these cautions in mind, it is interesting to note that the results of the analysis show that commercial sites, generally most exposed to traffic, have the highest contribution of rubber while underdeveloped or rural sites barely measure any rubber.

In the course of the careful evaluation of the monitoring network in each city, monitoring sites were also rated on the basis of local influences, including paved roads. Sites with an expected paved road influence (10 in all) had rubber concentrations twice as high as sites for which no such influence had been noted - 9.9 and 4.9 $\mu g/m^3$, respectively.

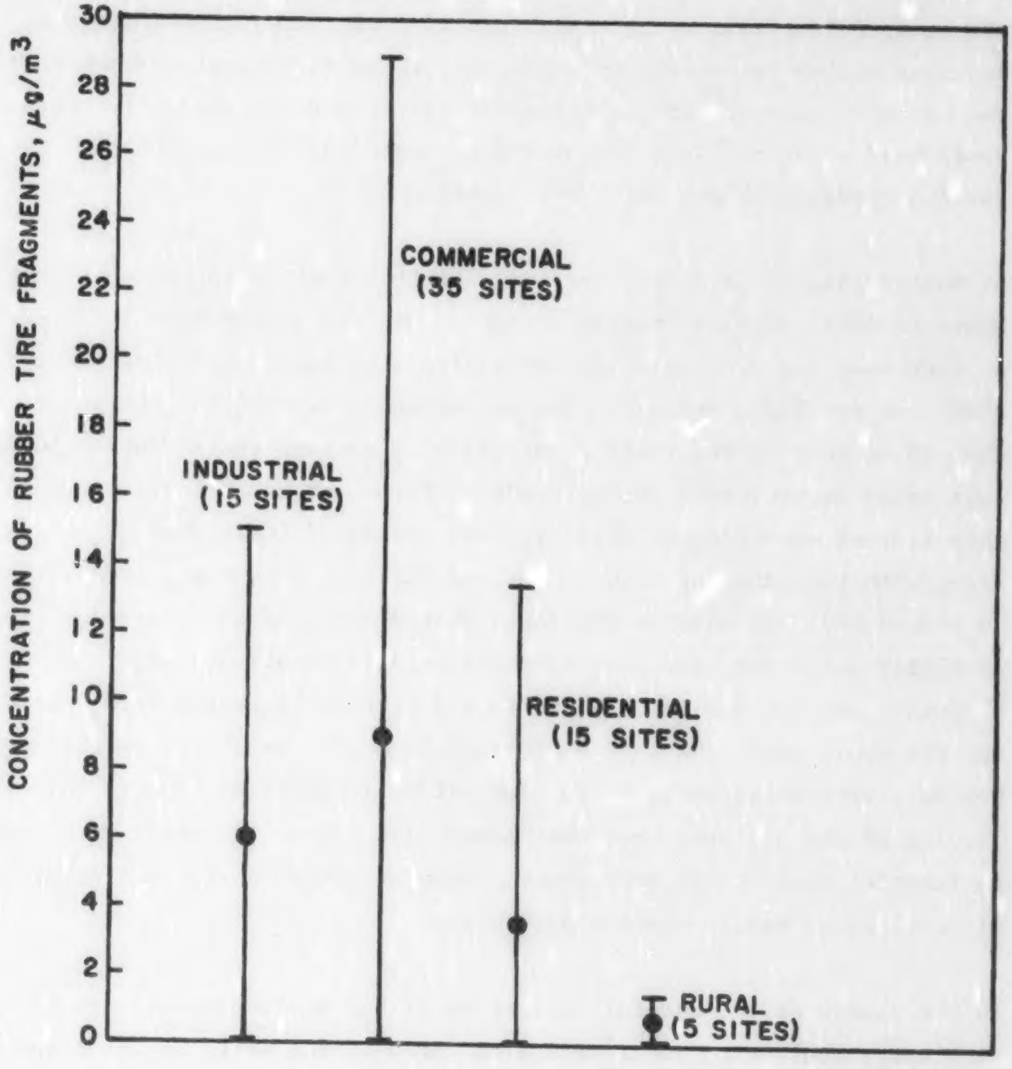

Figure E-7. Average and range of TSP loadings due to tire wear at different monitoring site classifications

The values found for rubber in the course of this study are several times what were expected based on the literature reviewed. The reason for this discrepancy is not apparent. This experiment may have been better formulated to give a good cross-section of values or the high levels may be an artifact of the monitoring site and filter selection. Currently, however, there is no reason to doubt the validity of these data.

Of some interest in planning for control is the particle size distribution of the rubber. The average size range of the rubber tire fragments (13 to 135 μm) is much larger than that of any other particulate identified in the microscopic analysis (See Appendix B). Some particles were found to be 200 μm in length. Normally, such large particles are not considered suspendible for any length of time and are too large to be of concern for inhalation. Despite their size, however, no difference was discernible in average concentrations of rubber by monitor height. Several monitors, 50 to 100 feet above ground level, measured concentrations of rubber in the 5 to 15 $\mu g/m^3$ range while other, lower monitors recorded no rubber.

Construction/Demolition

The movement of materials associated with construction and demolition activities usually results in the emission of particulates into the ambient air. Major demolition programs, whether using a ball and crane or blasting (low-yield), will emit particulates up to a height equal to that of the building being removed. On the other hand, construction involves much more movement of materials continuously for periods of several months to over a year. Emissions are generated by a wide variety of operations over the duration of the construction, including land clearing, blasting, ground excavation, and on-site traffic as well as the construction of the facility itself.

Two studies have attempted to estimate the total emissions from construction activity based on the size of projects underway. This is a very difficult task as most construction jobs, except for road construction, are different. In addition, particulate emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. Original estimates for an emission factor for particulates from construction were between 1.0 and 1.4 tons/acre/month.[16,17] A later revision to develop state-specific emission factors considered the average duration of construction projects in each state.[18] The resulting emission factors and total emissions due to construction in major counties for each of the AQCR's reviewed are given in Table E-7 along with the traditional source emissions.

The data in this table indicate that emissions from construction activity in most of the major counties reviewed in this study would be overwhelming in comparison to those sources traditionally considered. In all but one case the emissions from construction are comparable to or greater than traditional source emissions. When combined with the emissions from unpaved roads, the fugitive dust emissions in King County and Oklahoma County amount to over 50 times the traditional emissions.

To develop the emission factors used for deriving the emission estimates presented above, several ambient monitoring experiments were conducted.[16] These sampling studies were not conducted in urban settings but rather in more open terrain near construction sites where more surface preparation and travel on the construction site itself would occur. This may explain why the emission factors are so large.

Of greater importance to the use of these numbers in air pollution control planning are the findings of the above sampling studies with respect to the extent of the impact of the construction activity on ambient TSP levels. These studies showed that any effect that construction activity had on

Table E-7. COMPARISON OF FUGITIVE DUST EMISSIONS FROM CONSTRUCTION WITH TRADITIONAL SOURCE EMISSIONS IN MAJOR COUNTIES OF 14 AQCR'S

AQCR	Major county	Emission factors, tons per acre	Emissions from construction, tons per year	Emissions from traditional sources, tons per year	Ratio
Baltimore	Baltimore City	13.9	19,320	7,000	2.76
Birmingham	Jefferson	16.5	23,000	110,000	0.21
Chattanooga	Hamilton	16.2	N.A.	10,300	—
Cincinnati	Hamilton	17.0	109,650	56,100	1.95
Cleveland	Cuyahoga	17.0	202,300	210,000	0.96
Denver	Denver	15.7	46,000	9,700	4.75
Miami	Dade	15.7	39,410	8,000	4.93
Oklahoma City	Oklahoma	17.2	85,140	2,600	33.26
Philadelphia	Philadelphia	17.4	292,230	31,600	9.24
Providence	Providence	11.2	7,200	7,800	0.92
San Francisco	San Francisco	17.5	147,180	4,800	30.66
Seattle	King	17.2	204,680	7,300	28.12
St. Louis	St. Louis City	16.5	68,800	15,600	4.40
Washington, D.C.	District of Columbia	13.4	12,060	5,600	2.15

TSP concentrations was limited to within less than a mile from the construction site. In one experiment, the contribution, if any, of the construction activity to levels measured at monitors more than a mile from the construction site could not be distinguished from other, more local influences. In another experiment, a monitor approximately 4000 feet from a construction site did not reflect any measurable impact from the construction. On days of heavy construction activity, other sites closer to the activity recorded concentrations 100 $\mu g/m^3$ or more above levels measured when there was no activity.

City Study Findings - To help provide an understanding of the impact of construction activity on local and city-wide TSP levels, data on current and recent construction were gathered in several of the cities studied under this effort. Initial efforts to try to relate particular parameters of construction activity, such as building permits and dollars of new construction. to city-wide trends in TSP concentration failed in each of the cities for which it was tried (Providence, Philadelphia, Denver). As these data were collected on an annual basis, the impact of construction could not be isolated from that of meteorology and traditional source emissions. In addition, the type of data available for construction activity was not applicable to the size or the type of activity underway. Building permits are required regardless of the size of the project, and cost may refer more to the types of materials being used in construction than to size.

Therefore, the remaining effort was primarily devoted to estimating the impact of known major construction on nearby monitors. The findings are discussed at length in the respective city reports and are summarized below.

> Baltimore - Baltimore City has been conducting a large urban renewal program over the past 10 years, resulting in a considerable amount of demolition, construction, and rehabilitation; highway construction has also been underway for the

past 3 years. Four monitoring sites within 1 mile of construction showed an increase in TSP levels while the average values at other sites were declining. If similar declines had occurred at those sites near construction, their TSP levels would have been an average of 11 $\mu g/m^3$ lower in 1974. Road construction progressed to within one block of one monitor in 1974; its TSP level was 19 $\mu g/m^3$ higher in 1974 than in 1973.

Cincinnati - Urban renewal and highway construction have been prominent over the past 15 years, predating much of the monitoring network. No substantial impact on any one monitor could be established and, on an average, those sites potentially influenced by construction activity showed no difference in trends when compared with other monitors.

Denver - A comparison of total construction activity, through the use of permits and dollars of construction, with city-wide TSP levels failed to produce any correlation. However, fluctuations of 10 to 15 $\mu g/m^3$ in annual geometric means at several monitors over the past 5 years were interpreted by the state agency to be caused by nearby construction and urban renewal activity.

Miami - The 1974 construction activity associated with sewer installation for a residential neighborhood showed no measurable impact on the TSP levels at a monitor several blocks away.

Oklahoma City - Monitors in the downtown area where urban renewal has been underway for over 5 years have some of the highest values reported in the city, averaging about 10 $\mu g/m^3$ higher than in other parts of the city. However, a comparison of the trends at these sites versus those at other sites showed no apparent difference. The monitors started operation after the urban renewal effort.

Philadelphia - Extensive analyses of construction activities and TSP levels were conducted in Philadelphia on several levels of data - city-wide, administrative area, and site-specific. The city-wide and administrative areawide analyses showed no noticeable relationship between construction activity and measured TSP concentrations. A review of individual construction activity and nearby monitoring sites did not provide any definitive correlation between TSP levels and distance from the construction activity. The results indicated some probability that construction activity would affect measured air quality levels within 4000 feet of the activity, but wide-scale impacts were precluded.

Providence - Similar analyses were conducted in Providence; however, no impact on city-wide TSP levels could be detected over time. While a couple of sites were within 400 feet of major construction activity, the influence of the construction on measured TSP levels could not be separated from changes observed at other sites due to meteorological conditions.

St. Louis - Urban renewal projects have been in operation in St. Louis for the past 20 years, predating the monitoring network. Particulate levels have been decreasing over the years at all sites; however, at sites which are closest to the areas of construction, levels have been decreasing at a slightly slower rate than in other parts of the city. This suggests that the continuing emissions due to construction may be helping to maintain elevated levels at these sites; the projected average difference is 3 $\mu g/m^3$.

Washington, D.C. - A significant amount of construction has taken place in the Washington area in the last 2 years; in particular, the METRO transit system development is a focus of construction activities of various types around the city. According to the District agency's 1974 "Annual Report on the Quality of the Air in Washington, D.C.," subway construction influenced measured particulate concentrations at three sites, and a fourth site (CAMP) was felt to be subject to other construction activity. Trends at these four stations were compared to trends at other sites in the District of 1972-1974; the comparison suggested that the 1974 levels were elevated 10 to 15 $\mu g/m^3$, on an average, at the sites near construction. One monitor 600 yards from construction in 1974 showed levels 19 $\mu g/m^3$ higher than in 1973. Those monitors exposed to the cut-and-cover or surface type of construction were the ones which showed the increases, while a monitor near tunneling activity did not have higher levels in 1973.

Two other activities were available to indicate the impact of construction. At the CAMP monitor, a vigorous enforcement program was begun in May 1974 to eliminate fugitive dust from the construction site closest to the monitor. This program produced a substantial decrease in the number of violations of the 24-hour secondary standard (150 $\mu g/m^3$) from 16 during the first 4 months to four for the rest of the year. At another station, a month of construction for the foundation of a greenhouse only 100 yards from the monitor provided a monthly geometric mean 80 $\mu g/m^3$ higher than would have normally been expected.

The above findings illustrate that construction activity does have an impact on very local TSP levels but that the effect is not readily predictable. Construction will generally elevate concentrations downwind from the site for distances up to a mile. The amount of increase is related to the level of activity, type of activity, distance from the activity, and control measures employed. Monitors within half a mile of construction may have annual geometric means 10 to 15 $\mu g/m^3$ higher than normal. Therefore, if 10 percent of the monitors in an urban area are near construction activity, the calculated city-wide average TSP level would be 1 to 2 $\mu g/m^3$ higher than otherwise expected.

These measured impacts are much less than would be expected based on a simple interpretation of the emission levels for each county given in Table E-7. Obviously, the use of those emission levels must be restricted to input into modeling programs which adequately account for the fallout and deposition of particles. In addition, new emission factors to reflect the type and degree of activity and any control measures would be more appropriate. Future development should emphasize that construction's impact is felt most strongly on the short-term where conditions change from day to day.

Control Approaches - As with fugitive emissions (discussed in Appendix D), the control of dust from construction and demolition activities is most often approached through the use of nuisance or reasonable precaution regulations. Under these regulations, the air pollution control agency usually responds to complaints about fugitive dust and then requires whatever controls are felt necessary to restrict the emission of particulates. Such regulations are as stringent as the agency wishes to enforce them. In some cases when the agency has reviewed authority over construction permits, the construction firm is notified of the need to control fugitive dust and specific control measures may be suggested.

The property line regulation, which allows a certain increase in concentration as the air passes over the property and/or restricts the TSP concentration or opacity of the air crossing the property line, is also applicable to fugitive dust emissions from construction. This type of regulation is enforceable to the degree that quantitative limits are set; however, it requires a special monitoring network set up around the construction activity to provide the necessary data. An appropriate network may be expensive to set up and operate, and controls under this type of system are unlikely to be pursued to any greater degree than reasonable precautions.

A final type of regulation, used in only a few states, requires specific controls on particular operations. For instance, in Colorado the state agency has called out construction and demolition activities for control. Permits are needed for these activities and the types of control measures to be used must be described in the permit application. Fugitive dust control measures include, but are not limited to:

- wetting down, including prewatering;
- landscaping and replanting with native vegetation;
- covering, shielding or enclosing the area;
- paving, temporary or permanent;
- treating, the use of dust palliatives and chemical stabilization;
- detouring;
- restriction of the speed of vehicles on sites;
- prevention of the deposit of dirt and mud on improved streets and roads;
- disturbing less topsoil and reclaiming as soon as possible.

Specific requirements imposed by Colorado include the following:

> Sequential blasting shall be employed whenever or wherever feasible to reduce the amounts of unconfined particulate matter;
>
> Such dust control strategies as revegetation, delay of surface opening until demanded, or surface compacting and sealing, shall be applied;
>
> Haulage equipment shall be washed or wetted down, treated, or covered when necessary to minimize the amount of dust emitted in transit and in loading;
>
> These measures shall also be enforced during periods when actual construction work is not being conducted, such as on weekends and holidays.

Control methods such as watering and chemical stabilization have been evaluated and control efficiencies of 50 to 80 percent have been suggested.[16] Such control efficiencies are directly related to the extent of the control measure applied; e.g., amount and frequency of watering. Therefore, an agency should stipulate not only the type of control measure but also the degree of application. The construction firm then knows exactly what is expected of it and enforcement may be easier. The problem with this approach lies in the selection of the appropriate control measure for each type of activity.

CONCLUSIONS

While the above discussions have not covered all topics possible under the heading of nontraditional sources, they did center on those sources that have been identified as probable major influences. From these sources alone it is evident that there are contributions to the total TSP levels simply from man's activity and, in an urban area where man's activity is greatest, the contributions are the highest. Similarly, the closer to the activity, the larger the impact. These variations have been addressed above for each of the sources, but an overall combined assessment is needed to indicate the extent of the total impact of nontraditional sources on TSP levels, and thereby on the problem of attaining standards.

Because of the range of TSP levels that may be contributed by the various nontraditional sources, it is not possible to identify at this stage either the exact impact at any monitoring site or even the average impact in any one city. Such a determination would require extensive data and modeling, most of which are not available. Rather, the intent is to provide a measure of the range of impacts that may reasonably be expected in most situations and an understanding of the relative importance of nontraditional sources for standards attainment on a national basis. Therefore, this conclusion should not be taken as sufficient to preclude detailed analysis in each city but as guidance to the development of national priorities for further planning measures.

The average and range of TSP levels attributed to tailpipe emissions and tire wear were given in the above analyses by site type. Recognizing that there were wide ranges of values found at sites in different cities, average contributions can still be calculated. Tailpipe emissions provided an average level of TSP in industrial and commercial areas of 4 to 5 $\mu g/m^3$ and approximately 3 $\mu g/m^3$ in residential areas. Tire wear added rubber concentrations of 5 $\mu g/m^3$ at industrial sites, 8 $\mu g/m^3$ at commercial sites, and 3 $\mu g/m^3$ at residential sites.

Construction activity is more difficult to present on an average basis because of the wide range of possibilities that may occur. Some cities have construction currently underway at individual, widely dispersed locations which are not close to monitoring sites, while others may have similar activity but within one or more monitoring sites. Levels of TSP due to construction are expected to range between 0 and 15 $\mu g/m^3$ with the closer the monitor, the greater the impacts. If only one or two monitors out of a network of 20 are near construction activity, a city-wide average will only be affected by 1 to 2 $\mu g/m^3$ annual geometric mean.

However, in some cities major construction programs such as urban renewal and subways are going on in concentrated areas of the city. These activities are apparently causing higher-than-normal values at a large number of nearby monitors and will provide elevated average values in the commercial section of the city.

While construction is obviously a localized source, the reentrainment problem exists wherever there are roads and traffic. Since the level of reentrained matter could not be exactly determined through microscopy or elemental analyses, as with rubber and tailpipe emissions respectively, other measures were necessary. Based upon the analyses of average daily traffic and slant distances in Miami and Providence, the city-wide TSP contribution from reentrained dust can be assumed to be in the range of 15 to 20 $\mu g/m^3$. Also, by calculating the excess levels at residential, commercial, and industrial sites that could not be explained after accounting for nonurban levels and traditional sources (see Section III), the total nontraditional impact on the annual geometric mean TSP levels averages around 20 to 25 $\mu g/m^3$ at residential sites and 30 to 35 $\mu g/m^3$ at commercial and industrial sites. By subtracting the above levels estimated to be due to tire wear, tailpipe emissions, and construction, the average contribution due to reentrainment and any other nontraditional sources would be approximately 20 $\mu g/m^3$ at industrial monitors, 18 $\mu g/m^3$ at commercial monitors, and 14 $\mu g/m^3$ at residential monitors. (The higher levels at industrial monitors are likely the result of dirtier roads in the area.) These neighborhood levels of TSP are comparable to those calculated on a city-wide basis.

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APPENDIX F

INFLUENCE OF METEOROLOGY AND CLIMATOLOGY ON TSP LEVELS

GENERAL

The primary purpose of this appendix is to put into perspective the role of meteorology and climatology in determining which urban areas or regions of the country have met or are likely to meet the national particulate standards by summarizing the impact of certain meteorological variables and meteorological conditions on TSP levels in as quantitative a fashion as appears reasonable at the present time. Meteorological factors affect the rates at which locally generated particulates are introduced into the atmosphere, and control local dispersion and transport from the urban area. Additionally, the concentration of particulates in air as it enters an urban area is determined in large part by the air's recent trajectory and past meteorological conditions. And finally, depletion processes are also influenced by meteorological events.

This appendix provides a brief general discussion of the ways individual meteorological factors affect TSP concentrations, followed by a detailed presentation of attempts to quantify the affects of precipitation, wind speed, and degree days. The appendix ends with a summary of regional meteorological and geographical influences.

Precipitation

The effect of precipitation is twofold: (1) it cleanses the atmosphere by capturing particles within the cloud and by the washout of particles below the clouds; and (2) it suppresses fugitive dust.

Good summaries of the effectiveness of rainfall in removing particles have been presented by Engelmann[1] and Pasquill[2] and will not be repeated here. A basic reference is Chamberlain[3] in which the washout coefficient is shown as a function of the rate of rainfall and the terminal velocity of the particle. From Chamberlain's curves it is evident that the fraction of particles removed per unit time increases not only with increasing rainfall rate but also with increasing particle size. Calculations made from these curves show that sustained, light-to-moderate precipitation is extremely effective in removing the larger particulates, a conclusion that checks well with observational experience. For example, the use of $\ln(\chi/\chi_o) = -W_p t$ to express the fractional depletion of particle concentration χ where W_p is the washout coefficient and t is time, as done by Stern, et al.,[4] indicates that 50 percent of particles 8 μm in diameter and of unit density would be removed in about 35 minutes in a rain of 0.10 inch per hour. In addition to the inertia effects of the raindrops and particles which were considered in developing these curves, electrical effects, which are less well understood, are believed to play an important role in the removal of very small particles. Such small particles, of the order of a micron or less in diameter, have residence times within the atmosphere of several days.

Snow is also an effective cleansing agent. Although the feathery nature of the flakes and probable electrostatic charge suggest that snow is more efficient in cleansing the atmosphere than an equal amount of precipitation in the form of rain, this has not been firmly established.[1]

The effectiveness of rain in suppressing fugitive dust emissions is a result of the strong cohesive forces of absorbed water films surrounding soil particles. As a result of the relationship between soil moisture and fugitive dust emissions, soil must be very dry to be easily suspended by the wind. Although rainfall tends to create a surface crust on soil which also inhibits suspension, this crust is readily destroyed by any mechanical action, such as the passage of a vehicle. Heavy or sustained rainfall also is effective in washing paved streets. On the other hand, the amount of mud transferred after rainfall from unpaved parking lots and roads to paved roads by vehicles can result in a significant increase in street dirt in some areas.

Wind Speed

The effect of wind speed is also complex. As the speed of the wind increases, the effective volume of air available for dilution increases and, for constant source strengths, downwind concentrations tend to be inversely proportional to wind speed. However, in the case of particulates, total emissions are not invariant with windspeed since the wind is the natural agent by which soil and dust particles are resuspended. The amount of fugitive dust resuspended depends on the moisture content and nature of the soil (or dust) and the wind speed. At speeds below 10 to 15 miles per hour, however, the amount is probably neglibible even under dry conditions. At greater average speeds, and particularly under gusty conditions, fugitive dust contributions can be substantial. Wind speed also indirectly contributes to fugitive dust emissions by increasing the rate of evaporation, and hence speeds the drying of the soil and dust particles.

Wind Direction

On a local scale, the wind direction determines the polar distribution of pollutants around their sources, and hence is requisite to the understanding of source-receptor relationships and the design of source-specific sampling networks. On a regional scale, the background concentrations in the air masses entering an urban area have been determined by the past history of the air mass which is best estimated by trajectory calculations, although wind direction roses can also be helpful.

Temperature

Temperature, and seasonal temperature patterns, are the best single indicators of space heating requirements, and hence correlate with particulate emissions from these sources. Emissions from city to city for the same number of degree days will vary with the type of fuel burned. Temperature plays a part in fugitive dust emissions by affecting the evaporation rate of water and by its influence on the growth of vegetation.

Solar Radiation

In addition to being the driving energy source for weather systems, solar radiation relates to particulate emissions through temperature, evaporation, plant growth, and the formation of photochemical aerosols.

Stability

The stability of the air, as measured by the change of temperature with height, controls the rate of vertical turbulent diffusion and the mixing depth. It therefore is a measure of the dilution power of the atmosphere in the vertical. The diurnal variation of wind speed caused by the vertical transfer of momentum is closely related to the diurnal variation in stability.

Stagnations

Stagnating air masses permit the accumulation of pollutants and the development of stable transport patterns.

The geographic distribution of these and other meteorological and climatological factors influencing TSP levels will be discussed later in this section.

MAGNITUDE OF METEOROLOGICAL EFFECTS

Although the ways in which meteorological parameters affect TSP levels are quite well understood, the magnitudes of the various impacts have not yet been well defined. Among the reasons for this lack of definition are the complexity of the interrelationships among the meteorological parameters, the confounding effects of local particulate sources, and a general lack of daily TSP observations. This study attempted (1) to investigate quantitatively the effects of precipitation and wind speed (the most obvious meteorological influences) on day-to-day changes in concentrations, and (2) to make rough estimates of the impact of annual variations in meteorology when feasible. These results must be considered preliminary, but they do provide some guidance in judging meteorological impacts.

Short-Term Effects of Wind Speed and Precipitation

The most detailed day-to-day analyses were carried out using precipitation (expressed as its water equivalent in the case of snow), average wind speed, and TSP observations in Birmingham and Denver, with supplemental analyses in several other cities. Birmingham was selected because of its large data base with daily observations and the presence of major industrial sources; Denver was selected because of its recognized fugitive dust problem. Of the 14 cities studied, Denver has the lowest average annaul precipitation (15.5 inches) while Birmingham, with 53.2 inches, has next to the highest, being exceeded only by Miami, with 59.8 inches. In these studies of short-term variations, the effects of amount and frequency of precipitation and of average daily wind speed were investigated using local airport meteorological data. TSP levels were handled as concentrations in some cases and as ratios of 24-hour concentration to a smoothed average concentration in other cases to minimize seasonal effects and normalize the results. Weekend periods were omitted from the analyses because of the existence of strong weekly cycles in average TSP levels.

__Results in Birmingham__ — TSP levels at three sites were analyzed in Birmingham. Of these, one is industrial (North Birmingham), one is within the Central Business District (Downtown Birmingham), and the third (Mountain Brook) is in a residential area well removed from industrial sources and the principal center of urban activity. Data for 1974 only were analyzed at the two Birmingham sites where observations were made daily. At Mountain Brook, where observations were made every 6th day, 1973 data were also included to broaden the data base.

Daily TSP levels were plotted against wind speed at each site for three 48-hour precipitation categories: (1) ≤ 0.02 inch, (2) 0.03 - 0.24 inch, and (3) ≥ 0.25 inch.* Figure F-1 shows the results of little or no rainfall (≤ 0.02 inch) using Downtown Birmingham as an example. Two features of Figure F-1 are apparent. First, the range of concentrations is very large at the lower wind speeds but decreases greatly at higher wind speeds. Second, the average concentration decreases with increasing wind speed for speeds up to about 8 knots and then remains essentially constant. Furthermore, the decrease of average concentration with wind speed, as shown by the dashed line, is approximately linear from 2 to 8 knots, as would be expected if dilution were the controlling influence. The change in slope shown at 2.5 knots can be attributed to stagnation conditions at very low wind speeds. The plot of average concentration versus wind speed, shown in Figure F-1 for the Downtown Birmingham site, was transferred to Figure F-2 and similar curves added for the North Birmingham and Mountain Brook sites. It can be seen that the curve for North Birmingham reflects the same relationships as that for Downtown Birmingham, but that the average concentration at Mountain Brook appears to be invariant with wind speed. Thus one might postulate that the

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*The 48-hour precipitation period was selected initially on the basis of work done by Lazenka and Weir of the Philadelphia Air Management Services Laboratory. This selection is supported by results of this present study, reported later.

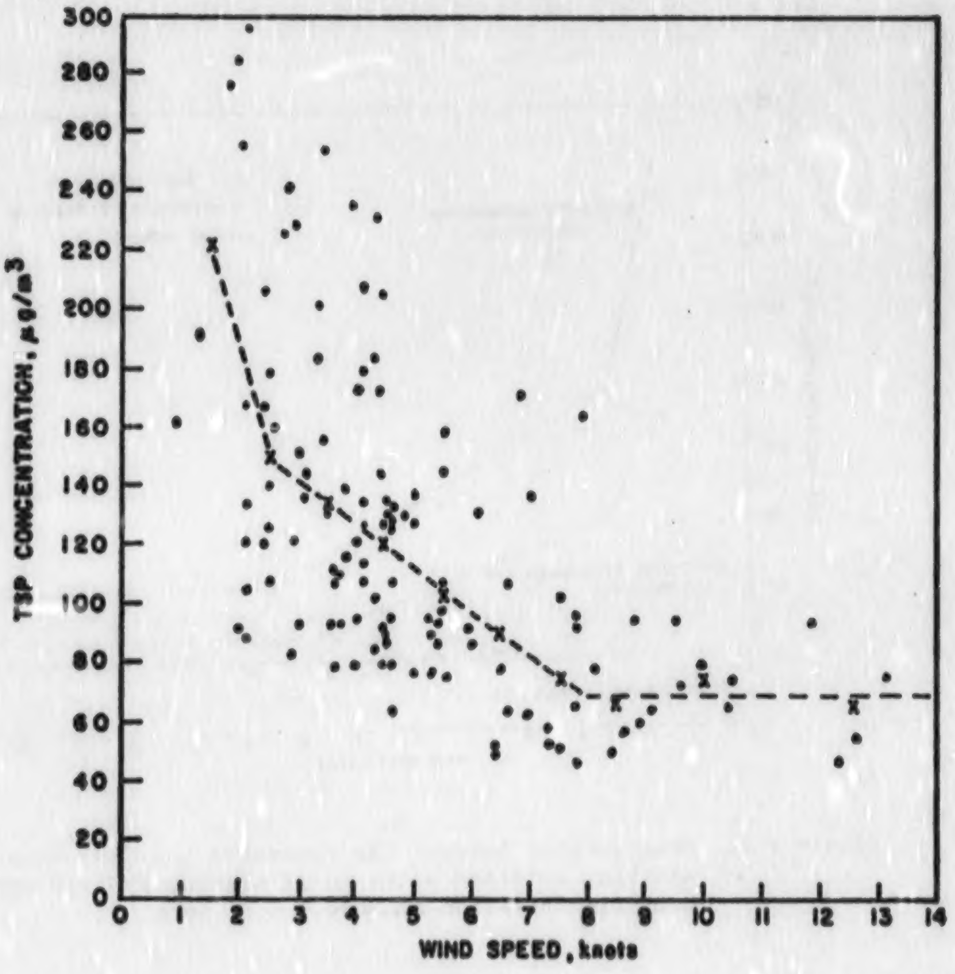


Figure F-1. Relationship between TSP levels and wind speed at the Downtown Birmingham site on days with 48-hour precipitation amounts ≤ 0.02 inch. The dashed line follows the geometric mean of the observations over selected class intervals

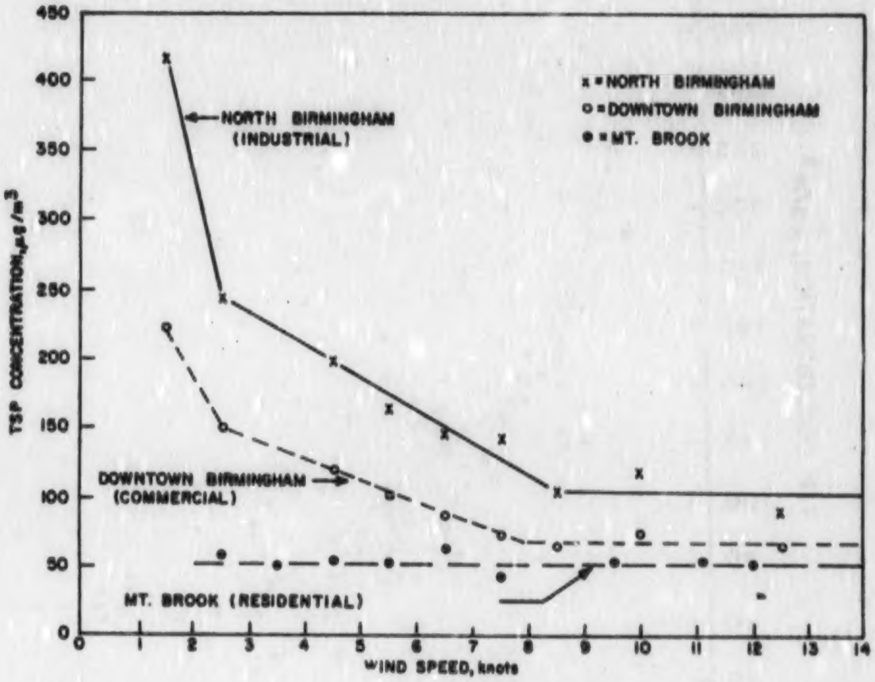


Figure F-2. Relationship between TSP concentrations and wind speed at three selected sites in Birmingham on days with 48-hour precipitation amounts ≤ 0.02 inch

Mountain Brook mean concentration of 52 $\mu g/m^3$ represents a concentration level below which the Birmingham mean concentrations will not drop by dilution. The tendency for particulate concentrations to be invariant with speed for speeds about 10 to 15 miles per hour, or perhaps to increase at high wind speeds has also been reported by Abel[5] in an investigation of particulates in Chicago. In this study Abel postulated that the departure from the dilution phase where concentration is inversely proportional to wind speed represents the contribution from fugitive dust emissions.

To avoid possible influences from seasonal patterns, Figure F-3 shows the relationship between relative TSP concentrations and average wind speed under dry conditions at the Downtown Birmingham site using the ratio of the 24-hour concentration to the running 5-week mean weekday concentration as the measure of relative concentration. Again, as in Figure F-1, the dilution effect appears to dominate the relationship below wind speeds of about 9 or 10 knots. Above this speed, concentrations average about 70 percent of the 5-week mean, as was also the case when the procedure was carried out using Chattanooga data.

A number of other possible relationships among TSP levels, wind speed, and precipitation at the three sites were also investigated using the Birmingham data. Table F-1 shows the geometric mean concentration for five precipitation classes at each of the sites and the mean value of the ratios of 24-hour to 5-week average concentration for the precipitation classes at the North and Downtown Birmingham sites. As expected, concentration decreases with increasing precipitation amounts at North Birmingham and Downtown Birmingham; however, no systematic change is shown by the more limited Mountain Brook data. At North Birmingham, the average decrease in concentration which occurred between periods when the precipitation on the observation and previous day totaled less than 0.03 inches and when the total exceeded 0.24 inches was 46 percent, while at Downtown Birmingham the average concentration decreased 32 percent.

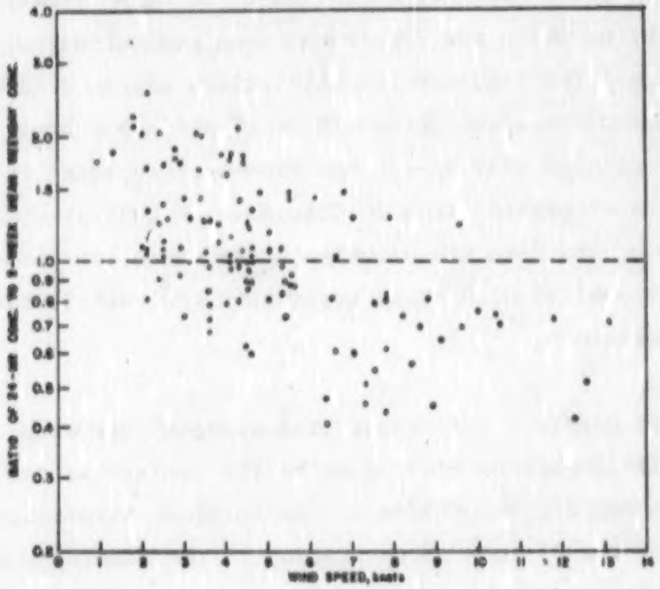


Figure F-3. Comparison of TSP levels to average concentration as a function of wind speed at the Downtown Birmingham on days with 48-hour precipitation amounts ≤ 0.02 inch

Table F-1. RELATIONSHIP BETWEEN 48-HOUR PRECIPITATION AMOUNTS AND TSP CONCENTRATIONS AT SELECTED BIRMINGHAM SITES, MONDAY THROUGH FRIDAY

48-hour precipitation in.	TSP levels							
	North Birmingham			Downtown Birmingham			Mountain Broo	
	n	μg/m³	Ratio	n	μg/m³	Ratio	n	μg/m³
0	99	195	1.14	100	117	1.08	43	53
0.01-0.02	27	141	0.88	27	96	0.88	3	41
0.03-0.24	38	128	0.75	39	85	0.81	12	56
0.25-0.99	56	106	0.66	57	80	0.77	17	41
≥1.00	28	103	0.65	26	75	0.72	4	46

Note: Concentrations and ratios are geometric mean values.

Since both wind speed and precipitation clearly affect particulate concentrations, concentrations were examined for various wind speed-precipitation regimes. Figure F-4 shows the effect of 48-hour precipitation amounts on TSP levels as a function of wind speed at the North Birmingham site. Mean values were plotted for selected wind speed classes and three precipitation categories. It is apparent from Figure F-4 that substantial reductions in concentration were brought about by precipitation at wind speeds below about 9 knots, but that at higher wind speeds concentrations show little variation with either precipitation or wind speed. Results obtained at the Downtown Birmingham site were similar. Thus suggests that an average minimum value for a given site can be reached either by increasing the wind speed to greater than about 9 knots, or, except at quite low wind speeds, by increasing the amount of precipitation.

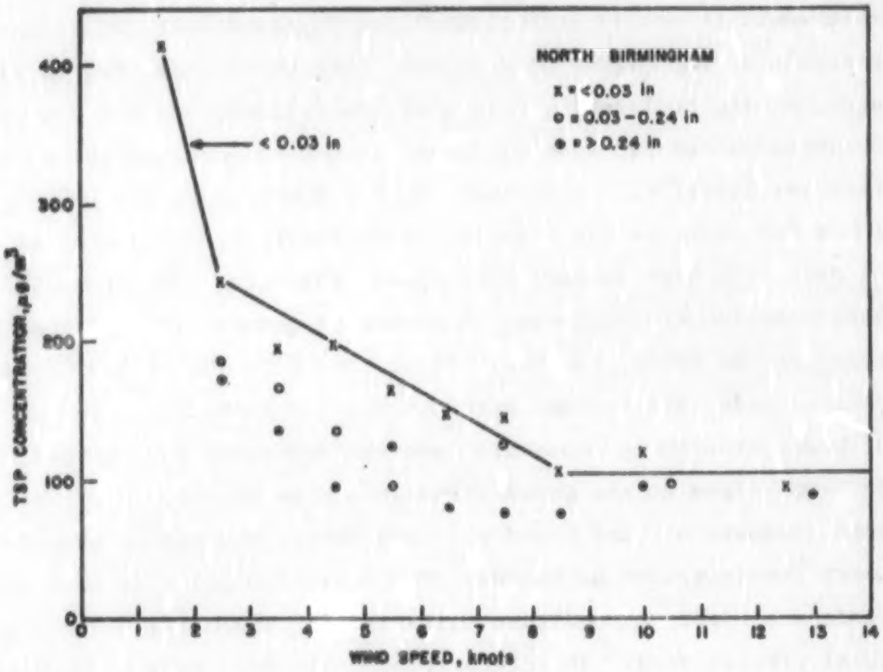


Figure F-4. Effect of 48-hour precipitation amounts on TSP concentrations at various wind speeds at the North Birmingham site

If the leveling off of the average concentration curve at higher wind speeds is due to fugitive dust emissions, as postulated, concentrations at these speeds would also be expected to respond strongly to precipitation. The rather minimal reduction actually observed perhaps is the result of the small sampling size available for these meteorological conditions. A large part of the reductions observed at speeds below 9 knots may reasonably be attributed to the combined effects of washout and reduced contributions by vehicular-induced reentrainment.

In a further attempt to isolate the contributions of fugitive dust to Birmingham TSP levels, geometric mean concentrations were calculated at the downtown and industrial sites for three wind speed classes under four different precipitation regimes. The first regime represented dry conditions in which the 48-hour precipitation amounts did not exceed 0.02 inch, and hence washout would be negligible but vehicular-induced reentrainment would be easily accomplished and fugitive dust emissions would be possible at the higher wind speeds. The three other regimes all begin with a day having at least 0.10 inch of precipitation on the day prior to the observation day but with different amounts of precipitation on the observation day itself (0 - 0.02 inch, 0.03 - 0.024 inch, and ≥0.25 inch). Table F-2 presents the results. Unfortunately, the number of observations on days with high average wind speeds following days with 0.10 inch of precipitation are very few. A number of general comments can be made based on the table, however. First, the dilution effect of wind speed is obvious under all regimes except heavy precipitation. Second, the effect of precipitation on concentrations the following day, if dry, appears to be very strong at the North Birmingham site but negligible at the downtown site (compare columns b and c). And third, the effect of moderate or heavy precipitation on the day of observation again is most obvious when winds are light, a condition which is most faborable for the washout of local particulates. In interpreting Table F-2, it must be remembered that certain wind speed and precipitation regimes are associated with weather situations which may have additional effects on TSP levels. For

Table F-2. AVERAGE TSP LEVELS FOR VARIOUS WIND SPEED AND PRECIPITATION CATEGORIES AT TWO BIRMINGHAM SITES

a. North Birmingham

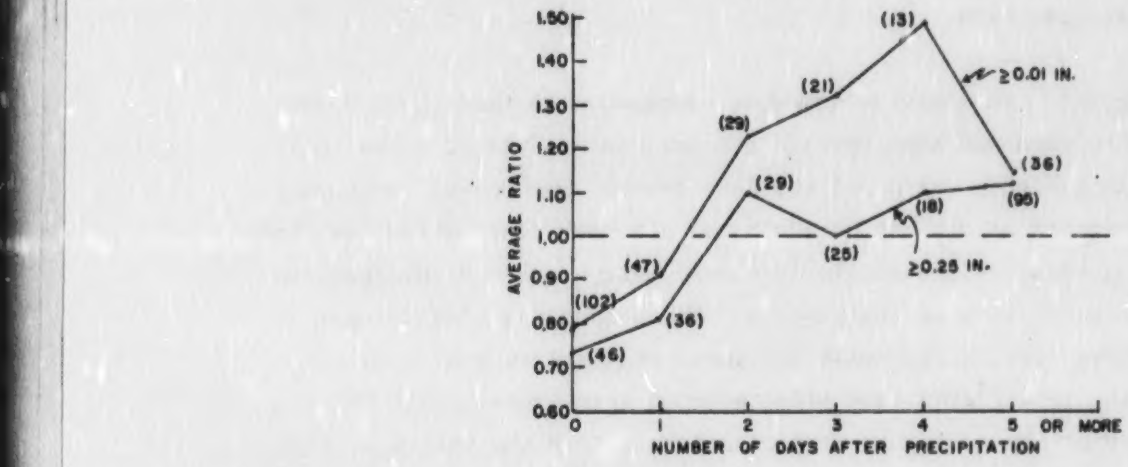
Wind speed, knots, a		48-hour precipitation, in.	Precipitation on observation day following days with at least 0.10 in. of precipitation, in.		
		0 - 0.02, b	0 - 0.02, c	0.03 - 0.24, d	≥0.25, e
2.0 - 4.9	n	74	16	7	9
	Geometric mean	210	167	140	94
5.0 - 8.9	n	39	14	4	3
	Geometric mean	145	95	108	87
9.0 - 13.9	n	9	2	1	3
	Geometric mean	106	74	37	78

b. Downtown Birmingham

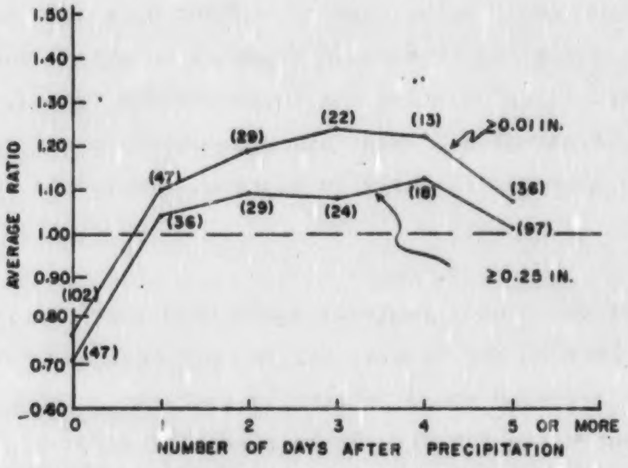
Wind speed knots, a		48-hour precipitation, in.	Precipitation on observation day following days with at least 0.10 in. of precipitation, in.		
		0 - 0.02, b	0 - 0.02, c	0.03 - 0.24, d	≥0.25, e
2.0 - 4.9	n	74	16	7	9
	Geometric mean	132	129	111	59
5.0 - 8.9	n	40	14	4	3
	Geometric mean	85	87	72	84
9.0 - 13.9	n	10	2	1	3
	Geometric mean	71	76	52	62

example, the highest concentrations of all tend to occur under stagnating conditions typified not only by light winds and no precipitation but also by subsidence and little vertical exchange in the lower atmosphere. Additionally, some of the differences between the various columns of Table F-2 may be caused by systematic differences in wind directions which can affect not only the impact of local sources but control entering background concentrations as well. One should therefore be cautious about using the differences in concentrations shown in Table F-2 to speculate in detail on the relative contributions of various source categories. Note, however, that approximately 30 percent of the loading measured at North Birmingham during the last half of a dry 48-hour period appears to have been eliminated by a moderate amount of precipitation prior to the measurement period, whereas no change was noticed at Downtown Birmingham. This indicates a substantial difference in the source characteristics of particulates reaching the two sites. Further, the fact that the North Birmingham reduction occurred at low as well as moderate wind speeds indicates that this part of the loading was not entirely wind induced.

The data at the two sites were examined in more detail to determine the average length of time precipitation is effective in reducing TSP levels. For this investigation, the ratio of observed 24-hour concentration to the 5-week running average concentration was used as the measure of concentration to permit easy comparison with results in other areas. The ratios were divided into six precipitation regimes and averaged, giving the results shown in Figure F-5. The calculations were carried out twice, using different levels of 24-hour precipitation to classify a day as one with precipitation. In one set of calculations, any day with measurable precipitation (0.01 inch) was considered to have had precipitation; in the second set of calculations, only days with at least 0.25 inch of precipitation were considered as days with precipitation. Figure F-5 shows that, on the average, TSP levels remain depressed the day after rain at North Birmingham. At Downtown Birmingham the levels return to near normal more quickly, as was pointed out earlier in the discussion of Table F-2. The effect of rainfall



a) NORTH BIRMINGHAM



b) DOWNTOWN BIRMINGHAM

Figure F-5. Duration of rainfall effectiveness in reducing TSP levels at two Birmingham sites. Number of observations is shown in parentheses. Ratio is ratio of 24-hour concentration to 5-week running mean concentration of different intensities is shown by the difference between the two curves for each site. The occurrence of the peak average ratio at 4 days after precipitation at North Brimingham reflects a few very high ratios apparently associated with periods of dry, light-wind, poor-dispersion conditions lasting for several days.

Results in Denver - An analysis somewhat comparable to that carried out with Birmingham data was also carried out for Denver; the principal difference was in the preparation of the data bases. The Denver monitoring network is operated on a 4-day schedule and a 4-year time period was chosen (1971-1974), instead of the single 1974 base year used in Birmingham, to increase the reliability of the results. The second major difference in the data sets was that a city-wide TSP index was used in Denver rather that attempting to differentiate effects among site types. This TSP index was obtained by averaging concentrations within the valley at five locations extending from Englewood in the south to Adams City in the north. These sites were: Englewood, Gates Building, School Administration Building, Sewer Plant, and Adams City. Again, weekend data were not used in the analysis. Data for the 4 years were pooled to obtain the reference concentration used in calculating the concentration ratios. The procedure followed was to calculate 4-year average monthly means and then to smooth these monthly averages slightly by means of a weighted running average (1-2-1).

The results of the Denver analysis again show that precipitation has a measurable effect on TSP levels, but in this case any relationship between concentration and wind speed is largely obscured. Table F-3 gives the average concentration for five 48-hour precipitation classes. The reduction shown by these average values in going from completely dry periods to periods with ≥ 0.25 inch of precipitation is 74 $\mu g/m^3$ or 48 percent. It should be borne in mind, however, that precipitation amount, in addition to being a measure of washout and the suppression of fugitive dust, is to some extent indicative of the more general meteorological conditions affecting diffusion rates as well. The average ratio between 24-hour concentration and the smoothed monthly mean concentration also shows a systematic decrease with increasing precipitation. A breakout of those observation days with precipitation that follow days with at least 0.10 inch of precipitation, as was done in Birmingham (Table F-2), yielded too few cases for meaningful conclusions.

Table F-3. RELATIONSHIP BETWEEN 48-HOUR PRECIPITATION AMOUNTS AND TSP CONCENTRATIONS IN DENVER, MONDAY THROUGH FRIDAY

48 hour precipitation, in.	5-station average		
	n	$\mu g/m^3$	Ratio
0	96	154	1.10
Trace	43	132	1.02
0.01 - 0.02	27	116	0.92
0.03 - 0.24	44	102	0.80
$\geq$ 0.25	22	80	0.61

Note: Concentrations and ratios are geometric mean values

Figure F-6 shows plots of the 5-station average TSP concentration and of the 24-hour to smoothed-monthly-concentration ratios against average airport wind speed for days with 48-hour precipitation amounts $\geq$ 0.02 inch. The lack of any useful relationship between wind speed and these measures of TSP level is obvious, with the possible exception that no above-average concentrations were observed when winds were in excess of 15 miles per hour.

To estimate the period of time over which precipitation is effective in reducing TSP levels in Denver, the 24-hour to monthly-mean-concentration ratios were grouped according to the number of days after precipitation and averaged. The following three precipitation levels were used to define a day with precipitation: (a) $\geq$0.01 inch, (b) $\geq$0.10 inch, and (c) $\geq$0.25 inch. The results are shown by the curves in Figure F-7, all of which

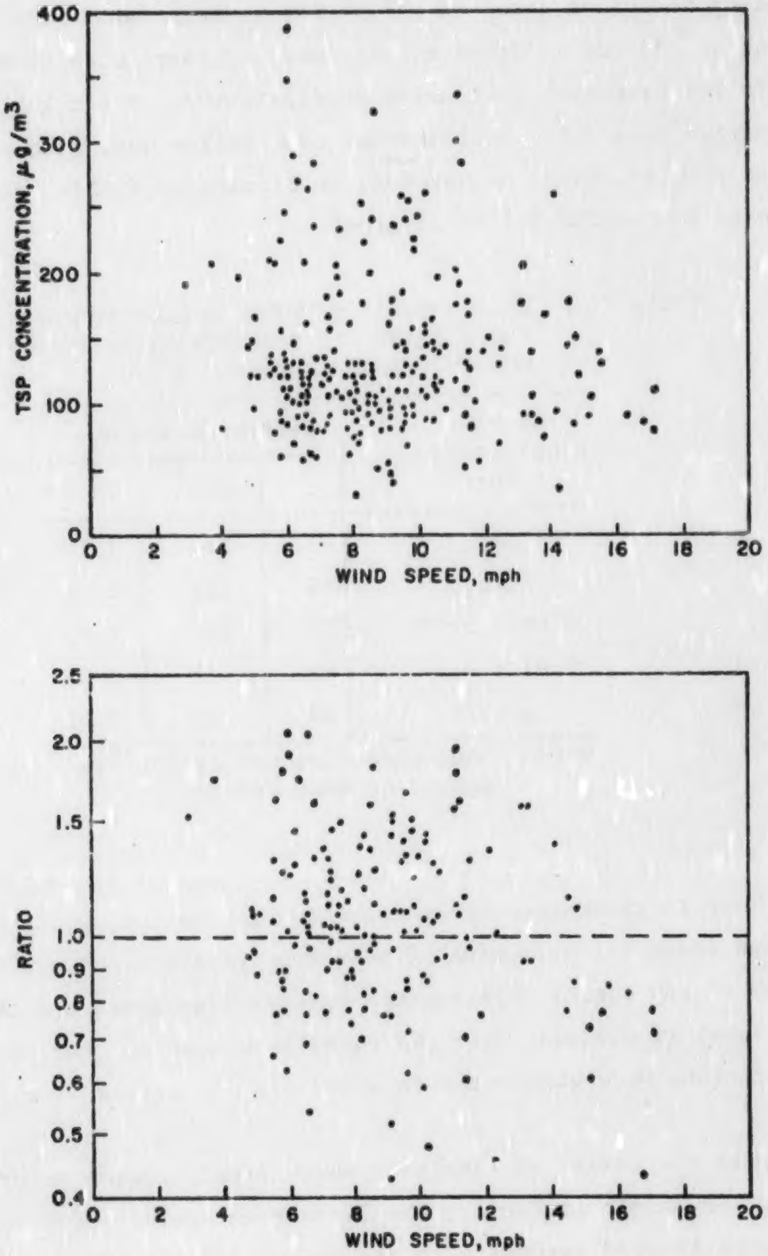


Figure F-6. Relationship between areawide TSP levels in Denver and wind speed on days with 48-hour precipitation ≥0.02 inch. Ratio is the ratio of 24-hour concentration to smoothed monthly concentration

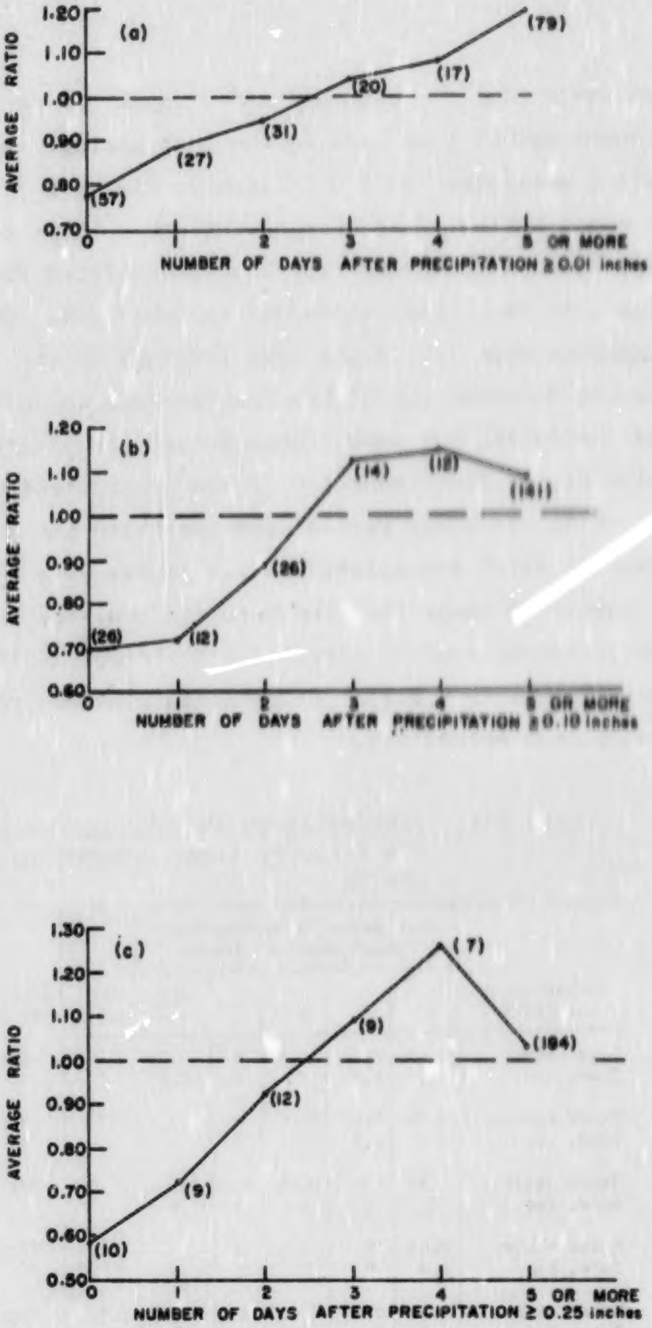


Figure F-7. Duration of precipitation effectiveness in reducing TSP levels in Denver. Number of observations is shown in parentheses. Ratio is the ratio of 24-hour concentration to smoothed monthly concentration indicate a recovery time of between 2 and 3 days. It is of interest to examine the seven values that make up the high average ratio found the fourth day after precipitation ≥ 0.25 inch in Figure F-7. To investigate the possible contribution of sanding operations to this high average ratio, precipitation amounts and type have been listed for the 5-day periods ending with each observation day in Table F-4. Of the 4 days with ratios greater than 1.0, 3 had some snowfall on the third and fourth days prior to the day that the higher-than-average concentrations were observed, and the fourth had snow 2 days before the observation day. Of the 3 days with ratios lower than 1.0, 2 had precipitation in the form of rain only during the 5-day period, and the third had snowfall on the day of observation which accumulated to 2.3 inches over a 13-hour period. Although the number of cases reported here are few, the results support the view that following sanding operations a widespread increase in particulate levels occurs as a result of vehicular induced reentrainment once the streets have become dry.

Table F-4. PRECIPITATION AMOUNTS AND TYPE FOR SELECTED 5-DAY PERIODS IN DENVER

	Days prior to observation — precipitation, inches						
Character of precipitation	4	3	2	1	Obs. day	TSP ratio	Date of TSP obs.
Water equiv.	0.41	0.17	0	0	0.09	1.56	4/06/73
Snow, ice	4.9	3.4	0	0	0.7		
Water equiv.	0.79	0.09	0.1	0	0	1.58	5/04/73
Snow, ice	2.1	0.9	0.1	0	0		
Water equiv.	0.56	0.01	0.10	0.19	0.02	0.91	7/23/73
Snow, ice	0	0	0	0	0		
Water equiv.	0.46	T	0	0	0	2.07	1/25/74
Snow, ice	4.6	T	0	0	0		
Water equiv.	0.40	0.20	0.06	0	0.13	0.71	3/22/74
Snow, ice	3.4	2.4	0.7	0	2.3		
Water equiv.	0.31	0	0	T	0	0.76	9/06/74
Snow, ice	0	0	0	0	0		
Water equiv.	0.64	T	0.21	0	0	1.25	10/16/74
Snow, ice	0	0	1.0	0	0		

Results in Other Cities - Similar, but more limited, studies of precipitation and wind speed effects on TSP levels were carried out using Chattanooga and Oklahoma City data. For the Chattanooga study, 1971 TSP levels measured at the City Hall were used. In Oklahoma City, 1974 data for three sites were used. Two of these were in the center city: Site No. 17 was at 800 N.E. 13th and Phillips Street, and Site No. 18 was a traffic-oriented site at 2045 N.W. 10th Street. The third site (No. 5) was located in the small community of Jones in argicultural land northeast of the city. Even though the number of observations at each of these three sites was quite limited, the sites were examined separately to see if any effect of site differences would appear. The results, presented in the same format as those of Birmingham and Denver, are given in Figures F-8, F-9, and F-10 and Table F-5. Briefly, the relative TSP level as indicated by the ratio of the 24-hour concentration to an average concentration over an approximate 5-week period is nearly invariant with wind speed up to about 8 knots in Chattanooga. At Chattanooga, the time needed to return to average TSP levels after precipitation is 2 days when all precipitation days are considered and increases to about 3 days when only days with $\geq$ 0.25 inch of precipitation are considered. The sketchy Oklahoma City data suggest a more rapid return to normal levels. Table F-5 shows a decrease in TSP levels of 22 $\mu g/m^3$ or 22 percent between days with negligible 48-hour precipitation amounts and days with $\geq$0.25 inch of precipitation at Site No. 17, but a decrease of only 9 $\mu g/m^3$ or 9 percent at Site No. 18 between corresponding periods, and no change in average level at Jones, where the mean concentration is low under both precipitation regimes.

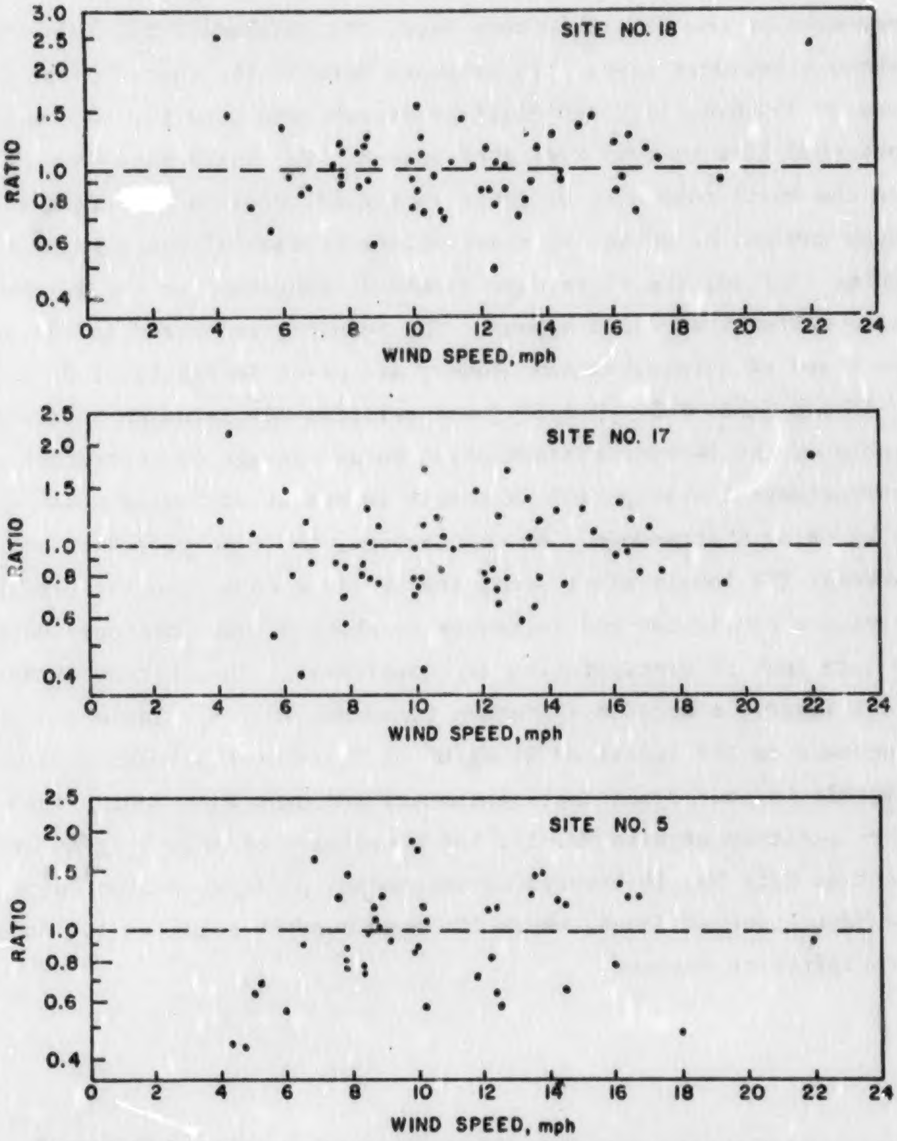


Figure F-8. Relationship between wind speed and relative TSP level at three Oklahoma City sites on days with negligible precipitation. Ratio is ratio of 24-hour concentration to 5-week average concentration

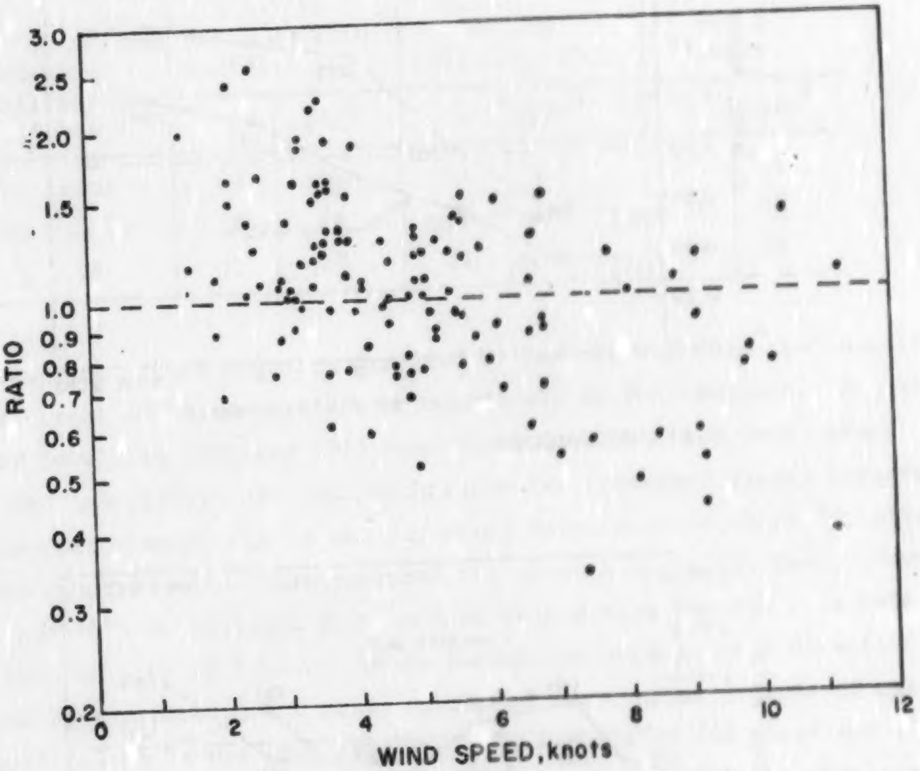


Figure F-9. Relationship between wind speed and relative TSP levels at the Chattanooga City Hall on days with negligible precipitation. Ratio is ratio of 24-hour concentration to 5-week average concentration the reductions attributed to precipitation may be biased due to typical sequences of weather and air mass changes associated with precipitation events.

- Precipitation is very effective in reducing TSP levels in highly polluted areas. In these areas, concentrations measured during the last half of a 48-hour period with precipitation $\geq$ 0.25 in. averaged approximately half of concentrations measured during 48-hour periods with negligible precipitation. In low pollution areas where concentrations are generally below 60 $\mu g/m^3$, the reduction was too slight to be detected.
- At locations with high TSP levels, average concentrations decrease steadily with increasing 48-hour precipitation amounts.
- Precipitation is most effective in reducing TSP levels on the day it occurs. Concentrations at typical urban sites (excluding clean residential areas) on days with measurable precipitation are about 75 to 85 percent of average values for the site and time of year.
- The effect of precipitation lasts, on the average, about 2 days, with the duration varying somewhat with location and the amount of precipitation.
- In nonindustrialized urban areas, average TSP levels do not appear to be related to airport wind speeds.
- In industrial areas where large contributions are made by point sources, average TSP levels decrease with increasing wind speed up to speeds of about 10 miles per hour and then remain invariant with wind speed.

The above conclusions have been drawn from average results. An interpretation of individual observations would require detailed examination of meteorological and emission data.

Effects of Annual Variations in Precipitation and Temperature

Multiple regression analysis was used to estimate the effects of annual variations in meteorological parameters over the 5-year period from 1970 to 1974 on the annual mean TSP level in the study cities. The three meteorological parameters initially considered as independent variables were precipitation, temperature (heating degree days), and wind speed. After initial calculations, plus reflection on the apparent lack of short-term correlation between wind speed and TSP level except in industrial areas, it was decided to exclude wind speed from the analysis. Allowance for a linear trend was made by designating 1970 as year 1, 1971 as year 2, and so on.

The data available for the 5-year analysis consisted of 11 sets of five annual averages for 10 of the TSP study cities.* Each set contained TSP annual means for each of three site types (industrial, center city, and suburban/residential) plus the meteorological data. Precipitation was entered as inches per year and heating demand as degree days in thousands.

In the analysis for which the results are given here, each site type average in each city was treated as a separate observation. Dummy variables were used to permit different intercepts for the several cities and the three site types, while the meteorological effects were estimated based on data from all cities. This approach in effect assumes that the meteorological parameters operate in roughly the same manner throughout the country, which is clearly neither an obvious nor a trivial assumption. Previous analyses that permitted the meteorological effects to differ from city to city did indicate that the effects found in the various cities were quite similar in magnitude, and it is on this basis that the assumption was made.

The resulting equation was:

$$TSP = C - 2.9Y - 0.43P + 2.5T$$

where TSP = annual geometric mean concentration in $\mu g/m^3$
C = constant in $\mu g/m^3$
Y = year, 1 to 5

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*Cincinnati, Cleveland, Denver, Miami, Philadelphia, Providence, St. Louis (both Mo. and Ill.), San Francisco, Seattle, and Washington, D.C.

P = annual precipitation in inches

T = heating degree days in thousands.

Table F-6 gives values of the constant C for the 11 urban areas and three site types.

Table F-6. CONSTANTS FOR REGRESSION EQUATION RELATING TSP LEVELS TO METEOROLOGICAL PARAMETERS

Urban area	Site type		
	Suburban/ residential	Center city	Industrial
Cincinnati	84	100	124
Cleveland	122	138	162
Denver	93	109	133
Miami	83	99	123
Philadelphia	92	108	132
Providence	66	82	106
St. Louis (Mo.)	73	89	113
St. Louis (Ill.)	98	114	138
San Francisco	53	69	93
Seattle	58	74	98
Washington, D.C.	59	75	99

The implication of the general regression equation is that, within the study cities, concentrations have been lowering at the rate of 2.9 $\mu g/m^3$ per year over the last 5 years, that an increase of 1 inch in annual precipitation decreases the mean concentration by 0.43 $\mu g/m^3$, and that an increase in heating degree days of 1000 increases the mean concentration by 2.5 $\mu g/m^3$. This result can be used to get some feel for the magnitude of the effects of annual changes in precipitation and temperature on TSP levels within a city, and for the differences to be expected among cities due to these two meteorological variables. Examination of the variations in precipitation and temperature over the 5-year period in each of the 14 study cities showed that the smallest range in precipitation (6 inches) occurred in St. Louis while the greatest range (27 inches) occurred in both Chattanooga and Providence.

The minimum range for heating degree days was 188 in Miami and the maximun range was 1189 in Cleveland. The implied differences in TSP levels resulting from these annual variations in precipitation range from 2.6 $\mu g/m^3$ in St. Louis to 11. 6 $\mu g/m^3$ in Chattanooga and Providence, and the differences resulting from variations in heating requirements range from 0.5 $\mu g/m^3$ in Miami to 3.0 $\mu g/m^3$ in Cleveland.

It should be recognized that this equation was developed using both variations within the 10 individual cities and among these cities. The equation is an attempt to generalize the relationships between TSP levels and the three variables and should therefore not be expected to have great precision at any one location. Furthermore, no attempt was made to account for differences among the various cities in the mix of fuels used for space heating.

Seasonal Variations

Just as changes in the annual levels of precipitation and heating degree days can affect the annual TSP levels, so too may the seasonal variations. Whereas changes in climatological factors can be 20 percent or more on a yearly basis, they can often vary by an order of magnitude between seasons and months. Therefore, the impacts that meteorology and climatology have on TSP levels, and thereby the implications for control planning, are much more important on a seasonal basis.

In most of the city reports (Volumes III to XVI), various meteorological influences were investigated for each city by comparing the 1974 monthly mean TSP levels with the monthly meteorological data. In this discussion seasonal variations of several of the readily available meteorological parameters influencing TSP levels are illustrated by presenting normal monthly values (based on a 30-year period) for the 14 study cities.

Because of the wide geographical distribution of these cities, these variations provide a fair sample of the magnitude of seasonal changes likely to be encountered nationwide. In addition, 1974 monthly precipitation and TSP concentrations are presented graphically so that major relationships or lack of relationships between the two variables during a specific year may be seen.

The meteorological parameters presented by monthly averages are: wind speed, total precipitation, number of days with measurable precipitation, and degree days. The mean morning and afternoon mixing heights, taken from Holzworth,[8] are also given, but by season only. The monthly data are provided in bar graph format in Figures F-11 to F-16 and the mixing height data are listed in Table F-7. The mixing height data in Table F-7 for Denver, Seattle, Miami, Oklahoma City and Washington are given as tabulated by Holzworth; data for the remaining cities were interpolated from his isopleth maps.

Figure F-11 shows mean monthly wind speeds for the 14 cities. Significant features of this display are: (1) the annual average speed among the cities varies by a factor of two and ranges from 6.3 miles per hour in Chattanooga to 12.9 miles per hour in Oklahoma City, and (2) the seasonal variation pattern differs considerably from city to city. However, with the notable exception of San Francisco, wind speed is at a maximum during the spring or winter months, and at a minimum during the summer. In the case of Chattanooga, Birmingham, and Seattle, the minimum extends into the fall season.

Normal monthly precipitation amounts for the 14 cities are shown in Figure F-12. Annual precipitation among the cities varies by a factor of 4, ranging from a low of 15.5 inches in Denver to a high of 59.8 inches in Miami. The seasonal variation is highly dependent upon the location of the city. Extreme examples are the west coast cities with summertime minimums and Miami where large amounts of rain occur from May through October. Figure F-13 shows the average number of days with precipitation amounts equal to, or more than, 0.01 inches, and the

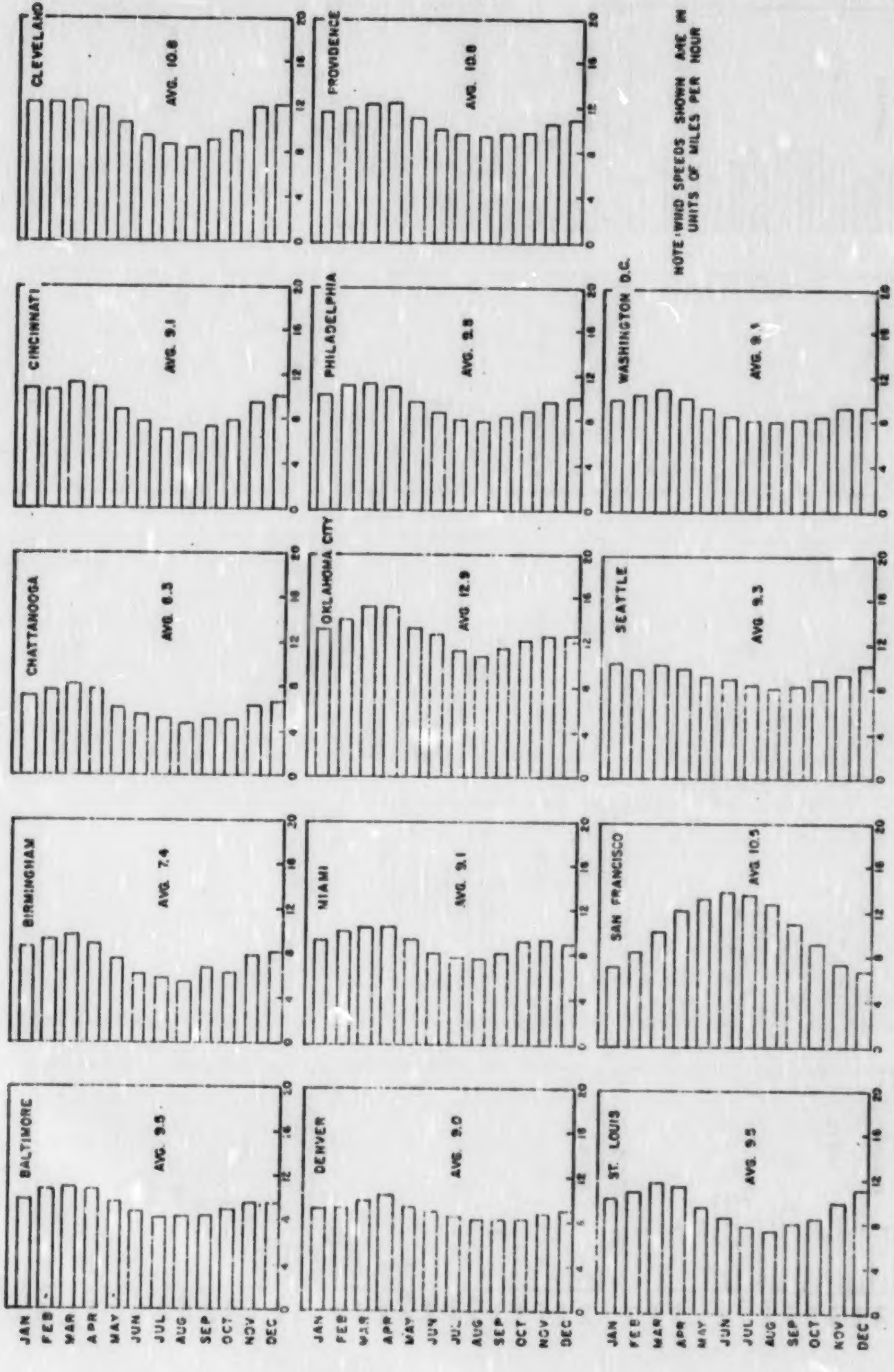


Figure F-11. Mean monthly wind speeds in 14 study cities (1941-1970)

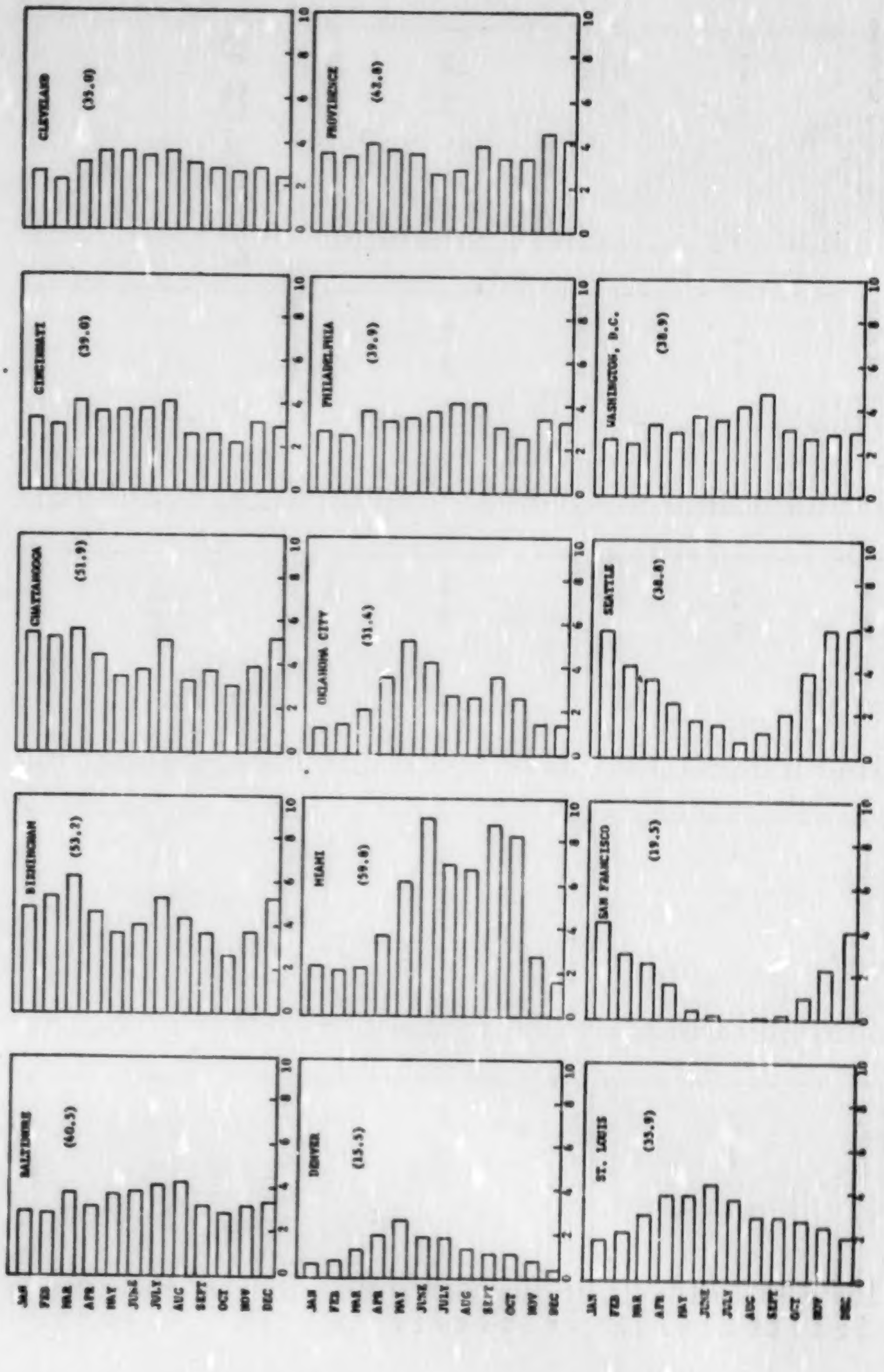
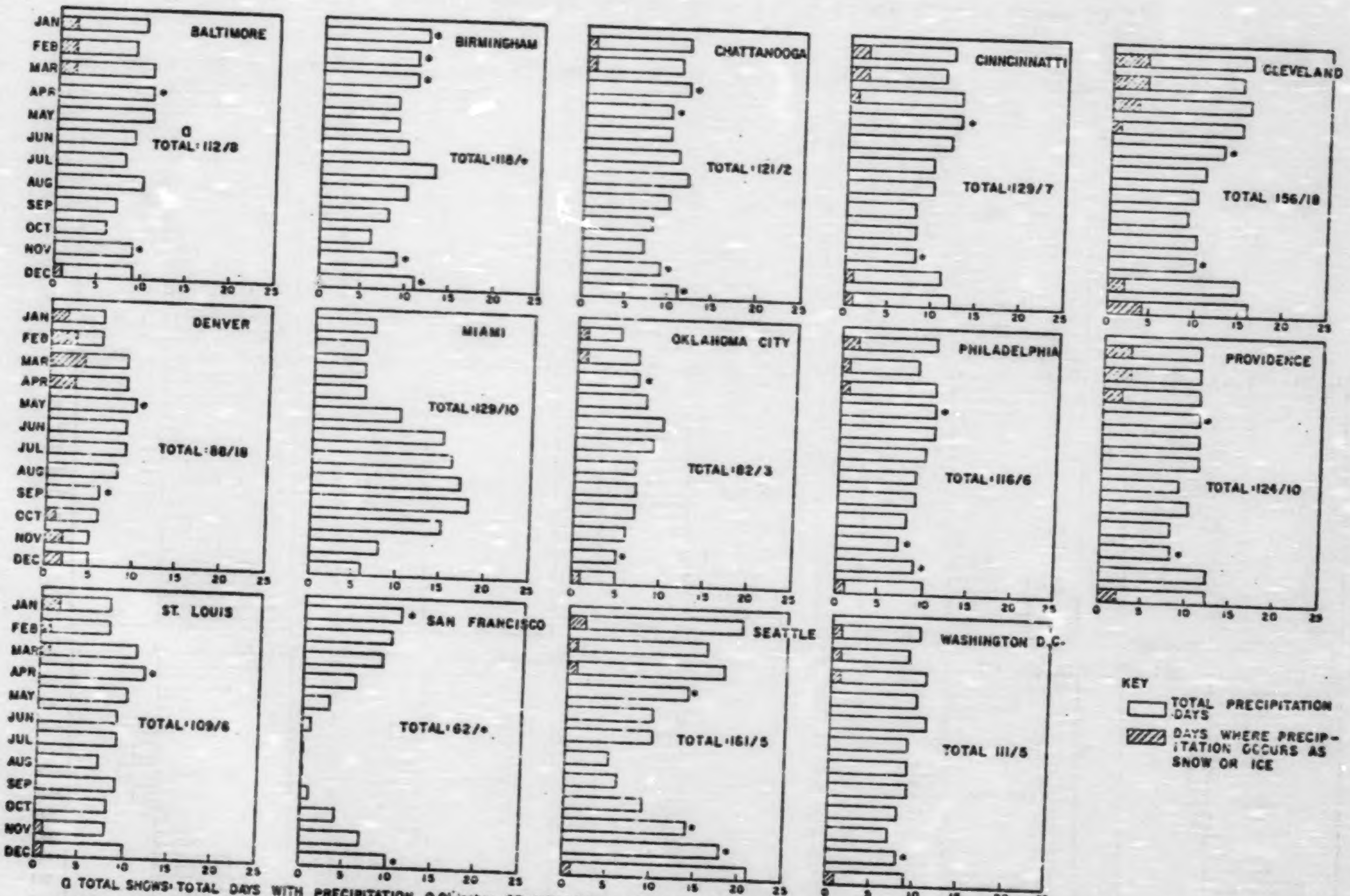


Figure F-12. Normal monthly precipitation in 14 study cities (inches). Annual averages are given in parentheses.



a TOTAL SHOWS: TOTAL DAYS WITH PRECIPITATION 0.01 inches OR MORE/TOTAL DAYS WITH PRECIPITATION AS SNOW OR ICE 1.0 inches OR MORE.
* INDICATES PRECIPITATION AS SNOW OR ICE OCCURS, BUT LESS THAN ONE-HALF A DAY.

Figure F-13. Average number of days with measurable precipitation in 14 study cities

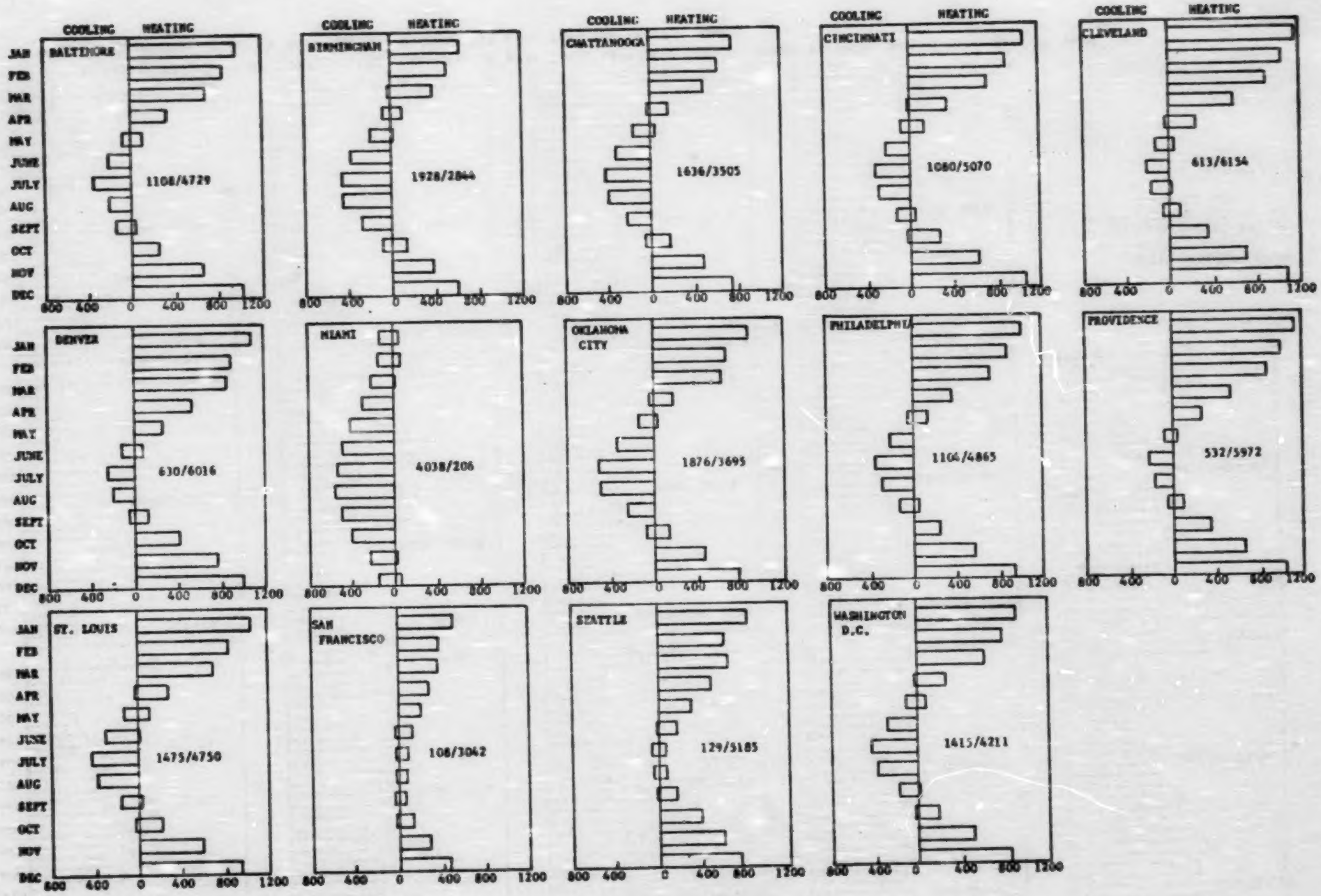
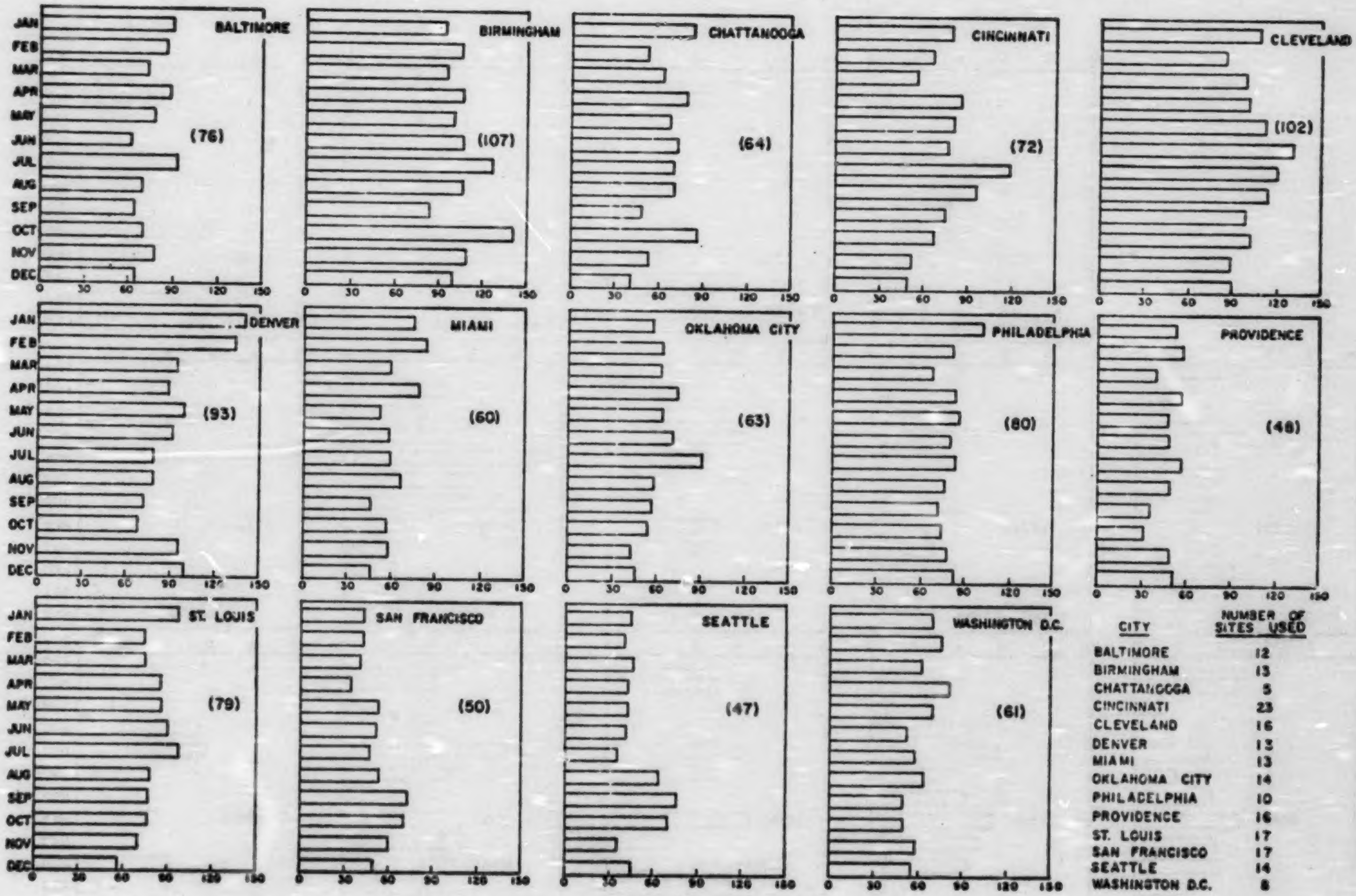


Figure F-14. Normal monthly degree days in 14 study cities (Base $65^{\circ}F$). Annual degree days are given as: cooling/heating.



CITY	NUMBER OF SITES USED
BALTIMORE	12
BIRMINGHAM	13
CHATTANOOGA	5
CINCINNATI	23
CLEVELAND	16
DENVER	13
MIAMI	13
OKLAHOMA CITY	14
PHILADELPHIA	10
PROVIDENCE	16
ST. LOUIS	17
SAN FRANCISCO	17
SEATTLE	14
WASHINGTON D.C.	8

Figure F-15. 1974 monthly geometric mean TSP concentrations in 14-study areas — annual means are given in parentheses

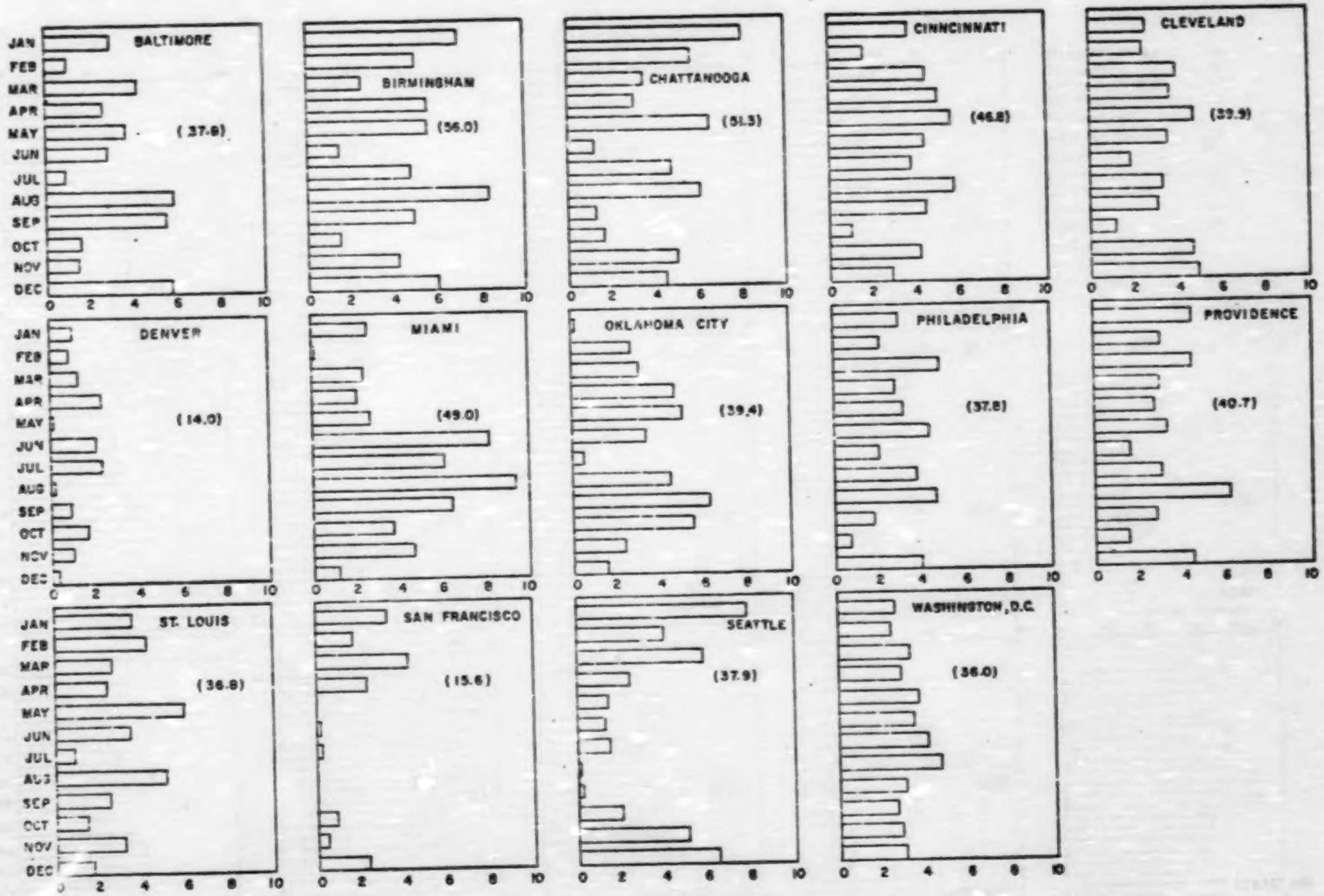


Figure F-16. 1974 monthly precipitation in 14-study cities (inches). Annual averages are given in parentheses.

Table F-7. MORNING AND AFTERNOON MEAN MIXING HEIGHTS

City	Time of day	Mixing height, meters			
		Winter	Spring	Summer	Autumn
Baltimore	a.m.	750	680	500	590
	p.m.	1,050	1,850	1,900	1,350
Birmingham	a.m.	500	470	420	350
	p.m.	1,050	1,700	1,850	1,450
Chattanooga	a.m.	510	520	420	350
	p.m.	1,100	1,870	1,900	1,500
Cincinnati	a.m.	550	600	380	400
	p.m.	900	1,730	1,700	1,350
Cleveland	a.m.	720	550	380	540
	p.m.	900	1,580	1,550	1,200
Denver	a.m.	219	423	255	174
	p.m.	1,482	3,070	3,458	2,161
Miami	a.m.	707	980	1,071	933
	p.m.	1,221	1,459	1,383	1,341
Oklahoma City	a.m.	342	457	367	343
	p.m.	859	1,506	1,862	1,302
Philadelphia	a.m.	900	800	650	750
	p.m.	1,000	1,600	1,700	1,200
Providence	a.m.	870	780	490	700
	p.m.	900	1,200	1,200	950
St. Louis	a.m.	430	490	330	370
	p.m.	800	1,550	1,650	1,300
San Francisco	a.m.	450	700	460	450
	p.m.	700	1,200	800	950
Seattle	a.m.	824	838	576	585
	p.m.	718	1,577	1,419	987
Washington, D.C.	a.m.	672	585	421	436
	p.m.	1,054	1,890	1,924	1,412

average number of days with snow or ice equal to, or more than 1 inch. Comparison of Figures F-12 and F-13 show roughly similar seasonal patterns with the principal exception being Cleveland where the number of days per month with precipitation is greatest during the winter and early spring, but the average amount of precipitation per month is low during the winter.

Figure F-14 shows the normal monthly heating and cooling degree days for the study cities and is of use principally in comparing space heating requirements among the cities. Rankings of the 14 cities by degree days and other meteorological parameters are given in Appendix A.

Figures F-15 and F-16 permit comparison between the monthly changes in TSP levels in each city and the monthly changes in the amount of precipitation. The TSP levels represent areawide concentration, with the number and types of sites included varying from one area to another, while the precipitation amounts are airport data. An overall impression gained from these two figures is one of greater regularity in the TSP profiles. Presumably this is due in part to smoothing resulting from spatial averaging, but also is likely to be a reflection of a number of seasonally-integrating factors. It should also be borne in mind that not only is showery type precipitation frequently spotty, but also that TSP sampling may not be carried out on days directly affected by the precipitation.

Although there appears to be no clear-cut seasonal trends in TSP levels in many of the 14 cities, three types of seasonal patterns can be noticed. The first type has a strong wintertime maximum and is represented solely by Denver. The second has a broad summertime maximum as shown by Cleveland, and to some extent by Cincinnati. And the third has a late summer and fall maximum, and is represented by Seattle and San Francisco.

The seasonal TSP pattern in Denver follows the same general pattern as other conservative pollutants, such as CO, and results principally from seasonal changes in stability and the height of the mixing layer. Inspection of Table F-7 shows that Denver's average morning mixing heights are the lowest of any of the cities and that its afternoon mixing heights are the highest, reflecting its dry climate and relatively intense solar radiation. Associated with this large diurnal variation in mixing height is a very pronounced seasonal change. The average of the morning and afternoon mixing heights shows the greatest seasonal change among the 14 cities, varying from 850 meters in the winter to 1856 meters in the summer. Also, it is generally agreed that the contribution from vehicular suspended street dust increases during the winter months due to sanding, but the magnitude of this contribution is still ill-defined.

The summertime maximum in Cincinnati and Cleveland are associated with the season of lowest wind speeds (see Figure F-11), and lowest morning mixing heights (see Table F-7). In Cleveland, low-level stability is reinforced in the summer months by undercutting cool air from Lake Erie.

In Seattle, the 3 months with relatively high average concentrations (August, September and October) occur at the end of the dry season and during the season with maximum inversion frequency and lowest morning mixing heights. In San Francisco, the highest average concentrations also occur at the end of the dry season as the strong summertime sea breeze regime comes to an end.

It is also interesting to note months with unusually high concentrations, shown in Figure F-15, compared to adjacent months and to check relative precipitation amounts during these periods. In general, months with high relative concentration had relatively little precipitation, but not always. Months showing the expected correspondence are: July in Baltimore; October in Birmingham and Chattanooga; July in Cincinnati; and July in Oklahoma City. On the other hand, January in Chattanooga had substantially higher concentrations than February, but also had more precipitation.

REGIONAL METEOROLOGY AND GEOGRAPHICAL FACTORS

The purpose of this discussion is to provide a brief overview of several large scale features of the meteorology and geography of the country which play an important role in determining TSP levels. These features include the general circulation pattern; the major storm tracks and resulting distribution of precipitation; wind speed with its multiple influences through dilution, transport, and contribution to fugitive dust emissions; frequency of low level inversions and stagnating air masses, with their associated poor dispersion conditions; major topographical features, which serve as barriers to air transport; and evaporation rate and an index used in estimating the potential for fugitive dust emissions.

Mean Flow Patterns

Except for southern Florida and the Gulf Coast, the contiguous United States lies in the belt of the prevailing westerlies. In very general terms, therefore, unpolluted air enters the continent from the west and accumulates particulates while traversing to the east coast. In actuality, however, this flow is impeded by mountain ranges, has superimposed upon it day-to-day weather patterns, and undergoes significant seasonal change. A more realistic view of average flow is given by Figures F-17 and F-18 which show the mean resulting surface winds at principal reporting stations during January and July. Large open arrows have been added to these maps to depict average flow conditions during these two months of maximum seasonal difference. During both seasons air enters the west coast from the Pacific, and flow through the mountain states, though rather ill-defined due to topographical influences, shows an average movement from the south and west. Very marked seasonal differences occur east of the Rockies, however. During January, major inflow from Canada dominates the pattern over the north central and northeastern states. In the far south, flow from the Gulf moves north over Texas, and air from the Atlantic crosses southern

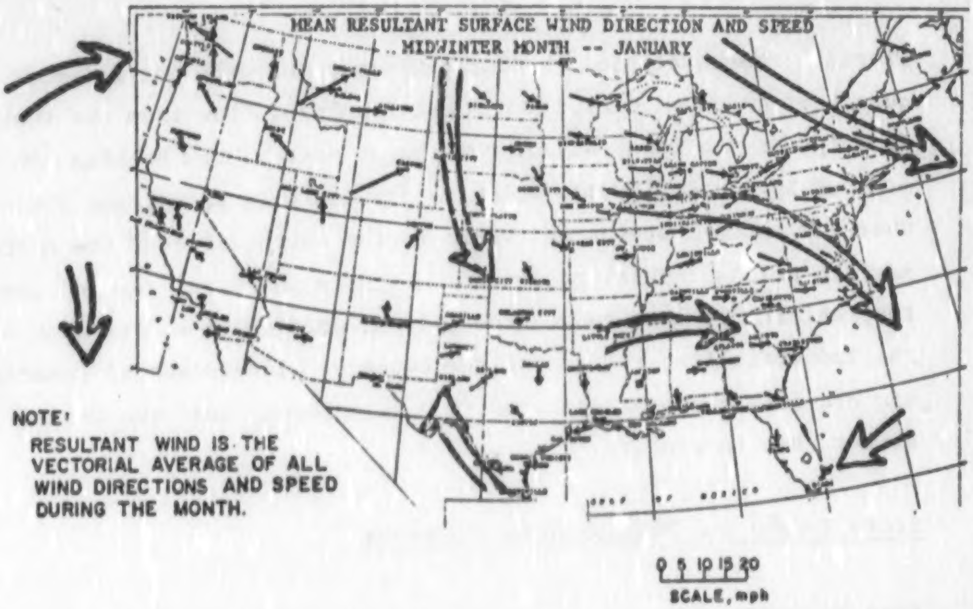

MEAN RESULTANT SURFACE WIND DIRECTION AND SPEED
MIDWINTER MONTH -- JANUARY
NOTE:
RESULTANT WIND IS THE
VECTORIAL AVERAGE OF ALL
WIND DIRECTIONS AND SPEED
DURING THE MONTH.
0 5 10 15 20
SCALE, mph

Figure F-17. Mean resultant surface winds for January. (Resultant wind map taken from Climatological Atlas of the United States[7])

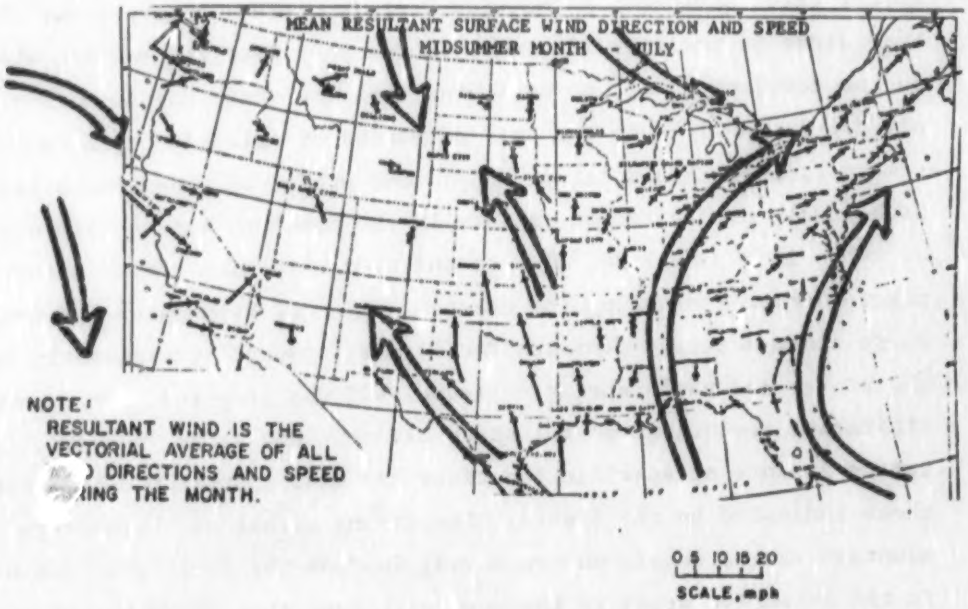

MEAN RESULTANT SURFACE WIND DIRECTION AND SPEED
MIDSUMMER MONTH -- JULY
NOTE:
RESULTANT WIND IS THE
VECTORIAL AVERAGE OF ALL
WIND DIRECTIONS AND SPEED
DURING THE MONTH.
0 5 10 15 20
SCALE, mph

Figure F-18. Mean resultant surface winds for July. (Resultant wind map taken from Climatological Atlas of the United States[7])

Florida. Northerly and southerly winds occur with nearly equal frequency at Oklahoma City, with a net resultant flow from the west. In July, in the mean, all of the states east of the Rockies are dominated by southerly flow which is particularly steady and strong over the central states and veers to the southwest over the northeastern states. This predominant south to southwest current provides the vehicle for long-range transport of particulates from many of the industrialized regions of the country. Incursions of Canadian air are less frequent and penetrate less deeply into the United States than in winter.

Storm Tracks and Precipitation Patterns

Some of the most frequent routes of cyclonic weather systems are sketched in Figure F-19. These paths have been drawn to give a general picture of the movement of low pressure centers and do not refer to the exact movement of individual storms. This figure shows that, regardless of their origin, many storms pass over the eastern states. In the development of storms moving from the west, moisture is supplied principally from the Gulf of Mexico or Atlantic Ocean, and the combination of this moisture supply and preferred storm paths lead to high annual precipitation amounts in the southern and eastern states, as shown in Figure F-20. The second area with high annual amounts of precipitation lies along the coastal region of Washington and Oregon where storm activity from the Pacific is frequent, particularly during the winter and early spring. Figure F-20 was prepared from mean precipitation amounts given for state climatic divisions, and precipitation amounts at specific locations may differ substantially from those indicated by the figure. The drying effect of the western mountain ranges on air masses moving in from the Pacific is reflected in the extensive areas in the west with less than 20 inches of annual precipitation.

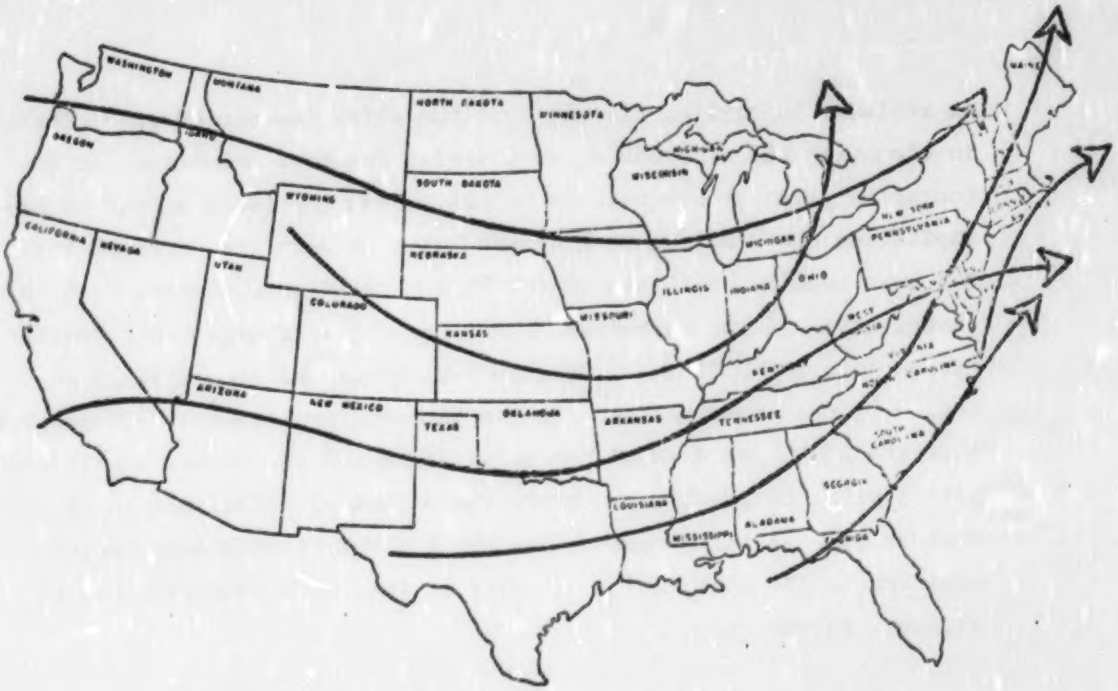

WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
OREGON
IDAHO
WISCONSIN
MICHIGAN
SOUTH DAKOTA
WYOMING
NEW YORK
PENNSYLVANIA
CALIFORNIA
NEVADA
UTAH
NEBRASKA
MICHIGAN
ILLINOIS
INDIANA
OHIO
COLORADO
KANSAS
MISSOURI
WEST VIRGINIA
KENTUCKY
VIRGINIA
NORTH CAROLINA
ARIZONA
NEW MEXICO
TEXAS
OKLAHOMA
ARKANSAS
TENNESSEE
SOUTH CAROLINA
GEORGIA
LOUISIANA
MISSISSIPPI
ALABAMA
FLORIDA
MAINE

Figure F-19. Frequent routes of cyclone centers

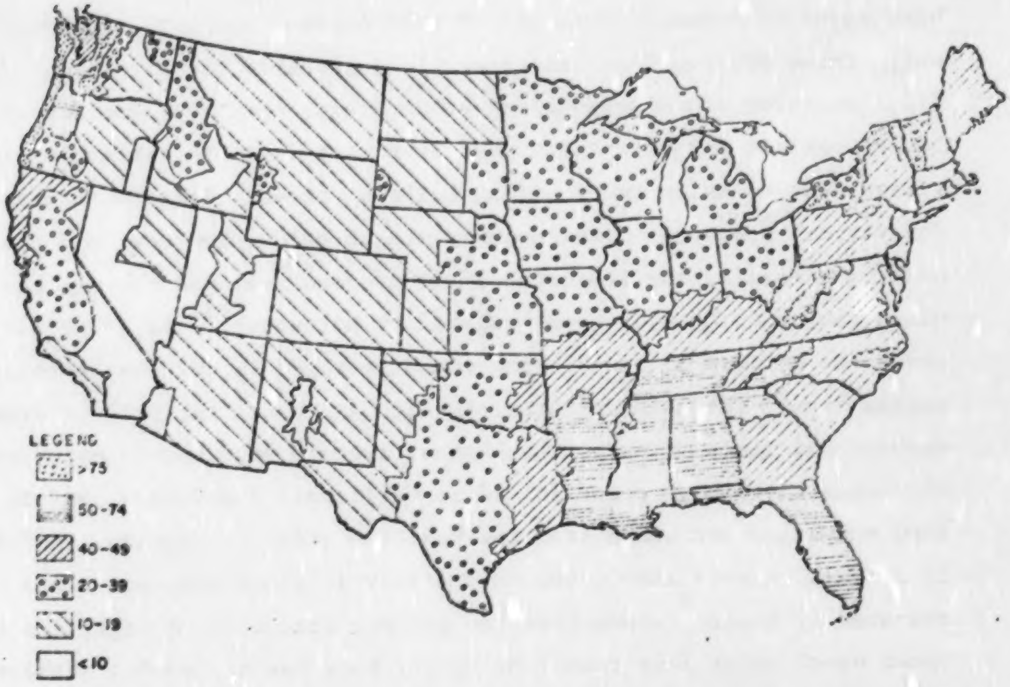

LEGEND
>75
50-74
40-49
20-39
10-19
<10

Figure F-20. Mean annual precipitation in inches. (Prepared from data in Climatic Atlas of the United States[7])

As reviewed in earlier discussions, the effectiveness of precipitation in cleansing the atmosphere, suppressing fugitive emissions, or encouraging plant growth depends not only upon the total amount of precipitation that falls during a year but also upon its distribution. The most readily available climatological statistic bearing upon this distribution is the number of days in a year with measurable precipitation (i.e., $\geq$ 0.01 in.). Figure F-21 gives the geographic distribution of this information. It can be seen from Figures F-20 and F-21 that the number of days with precipitation and the annual precipitation have similar geographic patterns; the principal difference is in the eastern part of the country where total precipitation amounts are greatest in the south and the number of days with precipitation is greatest in the north.

Wind Speed

Wind speed is commonly observed at well exposed airport locations. While these observations are generally acceptable for estimates of dilution rates above neighboring urban areas, they are less likely to be appropriate for use near ground or street level in estimating fugitive dust emission rates within built-up areas. Relative comparisons for various sections of the country are of value, however, and can be made by examining the isopleths of wind speed averaged through the mixing layer which have been prepared by Holzworth.[8] Figure F-22 shows the pattern of annual wind speed averaged through the morning mixing layer, the main features of which are characteristic of other seasons and times of day. The highest average wind speeds occur over Oklahoma; the lowest occur inland in California and Oregon, and in a band extending northward from the Mexican border to Wyoming. Moderately low wind speeds also occur extensively in the southeast. Maps prepared by Hosler[9] shows that the percent frequency of nighttime wind speed equal to or less than 7 miles per hour has a somewhat similar pattern; the fewest number of light nighttime winds are observed in

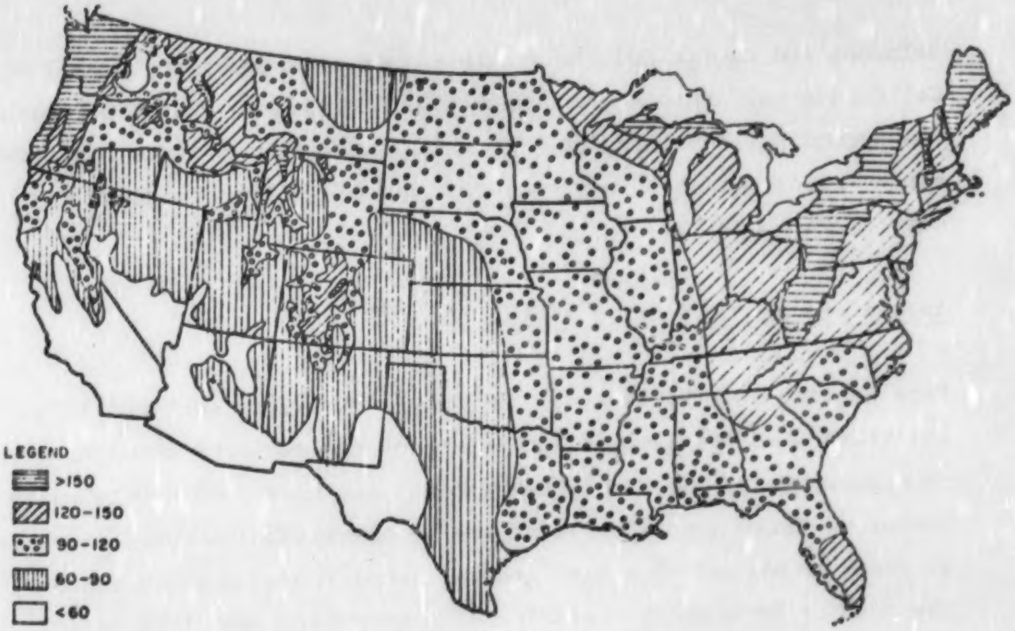

LEGEND
>150
120-150
90-120
60-90
<60

Figure F-21. Mean number of days with 0.01 inch. or more of precipitation in 1 year. (Prepared from data in Climatic Atlas of the United States[7])

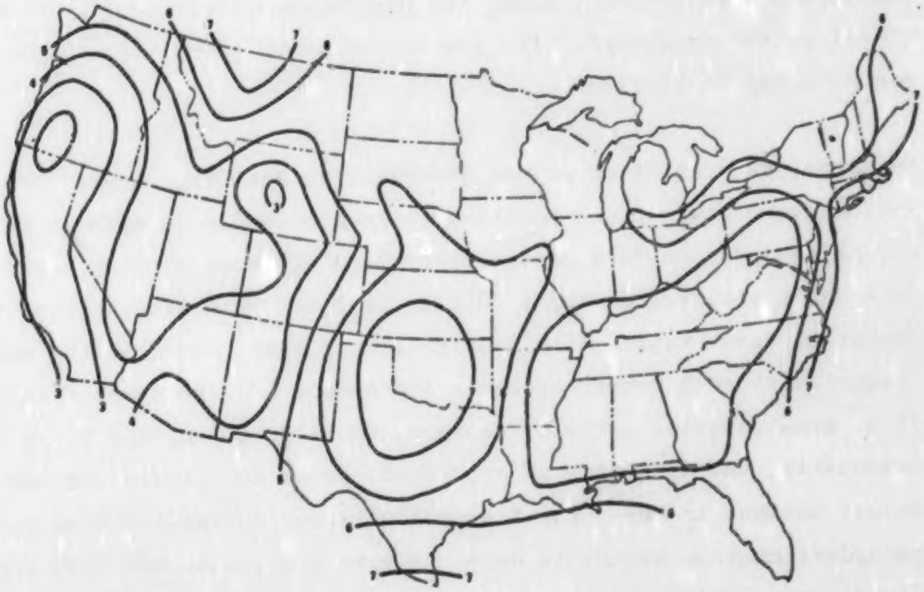


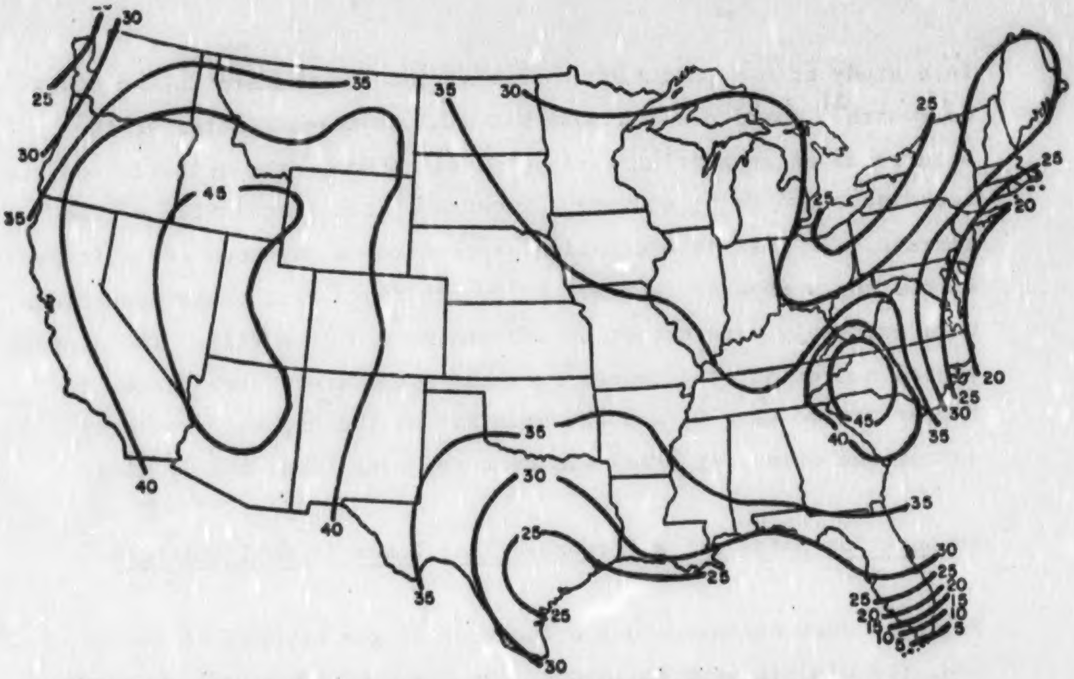
Figure F-22. Isopleths (m sec^{-1}) of mean annual wind speed averaged through the morning mixing layer (from Holzworth[8])

Oklahoma and Kansas and the greatest in a belt extending from lower California and Arizona northward through Nevada to southern Oregon. The second principal region with a larger number of light nighttime winds (greater than 70 percent) covers much of the southeastern part of the country.

Inversions and Stagnating Air Masses

Maps showing the frequency of low-level inversions (defined as an inversion with base within 150 meters of the surface) throughout the contiguous United States by season and year have been published by Hosler.[9] These maps show isopleths of inversion frequency in percent of total hours and thus make general comparisons from one region of the country to another possible. Figure F-23, taken from Hosler, gives annual isopleths and shows two centers of maximum frequency, one centered over western North Carolina and the other, larger and more elongated, centered in the west. Low frequencies occur along coastlines, particularly along the Washington-Oregon coast and much of the eastern seaboard. The lowest frequency of all is at the southern tip of Florida.

For detailed statistics on the distribution and frequency of stagnating anticyclones east of the Rockies, reference should be made to Korshover[10] who has summarized data on all cases of stagnation lasting for 4 or more days which occurred during a 30-year period. This study showed that the number of cases ranged from four to 16 per year, and that the maximum frequency in both number of cases and number of days stagnation occurred in an area covering parts of Georgia, South Carolina, and North Carolina. Seasonally, the frequency of occurrence peaks in October and has a secondary maximum in May. Low frequencies occur during the winter and a secondary minimum occurs in July. Figure F-24, sketched from data in a figure presented by Korshover, shows the geographic distribution of the average annual number of stagnation days for the 1936 to 1965 period.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30

Figure F-23. Annual inversion frequency in percent total hours (from Hosler,[9] p. 322)

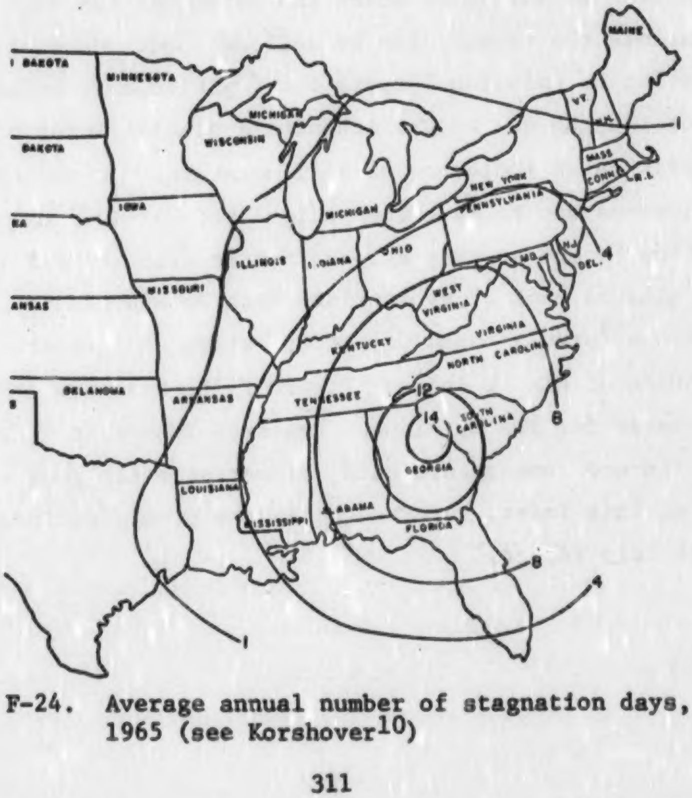
MAINE
DAKOTA
MINNESOTA
DAKOTA
MICHIGAN
WISCONSIN
VT.
N.H.
MASS
CONN.
R.I.
NEW YORK
PENNSYLVANIA
IOWA
MICHIGAN
ILLINOIS
INDIANA
OHIO
MD.
N.J.
DEL.
MISSOURI
WEST VIRGINIA
VIRGINIA
KENTUCKY
NORTH CAROLINA
OKLAHOMA
ARKANSAS
TENNESSEE
SOUTH CAROLINA
GEORGIA
LOUISIANA
MISSISSIPPI
ALABAMA
FLORIDA
1
4
8
12
14
8
4
1

Figure F-24. Average annual number of stagnation days, 1936 to 1965 (see Korshover[10])

In a study of air pollution potential for the western United States, Holzworth[11] carried out a somewhat similar investigation of the occurrence of stagnating anticyclones, although the criteria and study techniques had to be different because of the iregularity of the terrain. In this investigation an occurrence was counted if it persisted for 2 days or longer. Holzworth found that these conditions were extremely rare except during winter and late fall. The average annual number of occurrences over the total study area during an 8-year period was 20, and the area having the highest frequency (about one event per year) was centered over Idaho and Wyoming.

Evaporation Rates and a Meteorological Index of Soil Moisture

Fugitive dust emissions are a function of the dryness of the material and, for wind-induced emissions, the speed of the wind. Because of the many complicated relationships involved, no satisfactory index has yet been developed by which the potential for fugitive dust emissions across the country can be well defined. Current practice in the calculation of emission factors for fugitive dust emission sources has incorporated the use of Thornthwaite's precipitation effectiveness (PE) index as an indicator of soil moisture. In concept, precipitation effectiveness was to have been calculated by dividing the monthly precipitation by the monthly evaporation to find the P/E ratio. Because of the general lack of appropriate data on evaporation, Thornthwaite developed a formula based on precipitation and temperature for the calculation of his PE index. Figure F-25, based on a more detailed map prepared for EPA by Midwest Research Institute[12] from annual precipitation and temperature data, illustrates the geographic distribution of this index, referred to as the precipitation-evaporation index in this report.

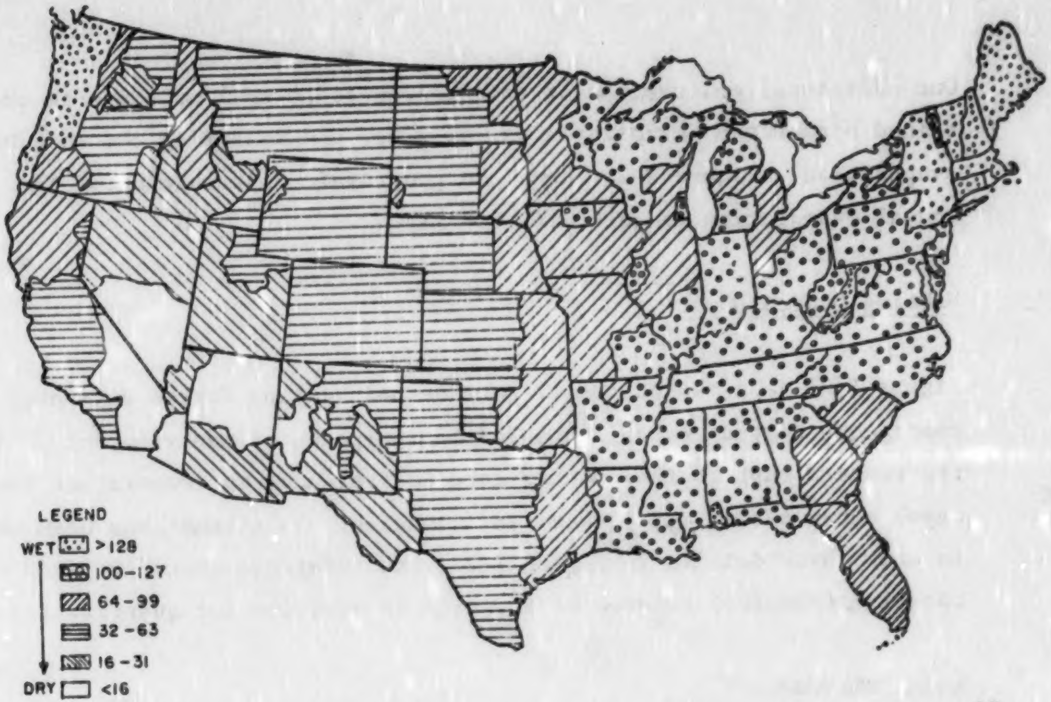
LEGEND
WET
>128
100-127
64-99
32-63
16-31
DRY
<16

Figure F-25. Precipitation-Evaporation (PE) values (after MRI Report[12])

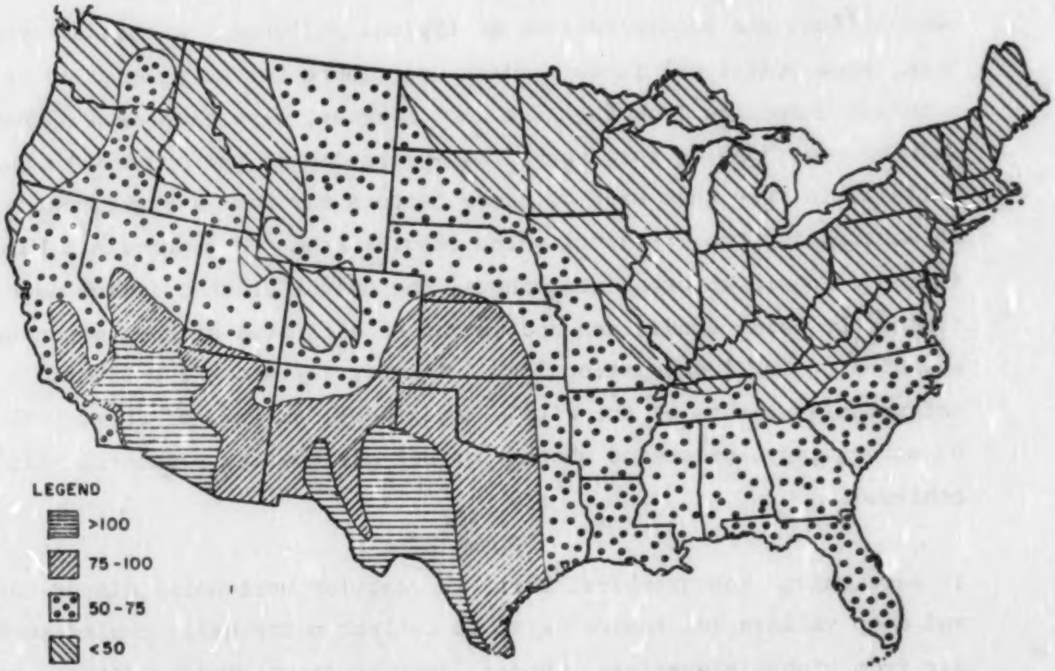
LEGEND
>100
75-100
50-75
<50

Figure F-26. Mean annual class A pan evaporation in inches (adapted from Climatic Atlas of the United States)

One additional observation of some relevance to soil moisture is obtained directly by exposing a pan of water and measuring the rate of evaporation. Figure F-26 shows the geographic distribution of the annual evaporation measured in this way.

Heating Degree Days

Figure F-27 is a map of the average annual heating degree days over the contiguous United States, prepared for purposes of overview only. In the western part of the country large differences in temperature (degree days) occur due to differences in elevation. No attempt has been made to show these details in Figure F-27, and reference should be made to the climatological records of the city in question for quantitative data.

LOCAL METEOROLOGY

The previous discussion has reviewed the principal meteorological factors which affect the concentrations of typical pollutants within an urban area, plus additional factors which contribute to the generation of particulate emissions from fugitive dust sources; maps have been presented showing how these factors vary from one region of the country to another. While it is true that each of these factors may have a significant impact in determining the TSP level which results from the particulate burden introduced into an urban atmosphere, the extent of that impact is controlled by local conditions and cannot be estimated without an understanding of the local meteorology. In many instances the favorable or unfavorable aspects of the city's topography, because of their influence on meteorology, determine whether or not air quality standards will be achieved.

In particular, topographical barriers restrict horizontal dispersion, and deep valleys and basins serve to collect nocturnally cooled surface air from higher elevations. Under light gradient wind conditions and

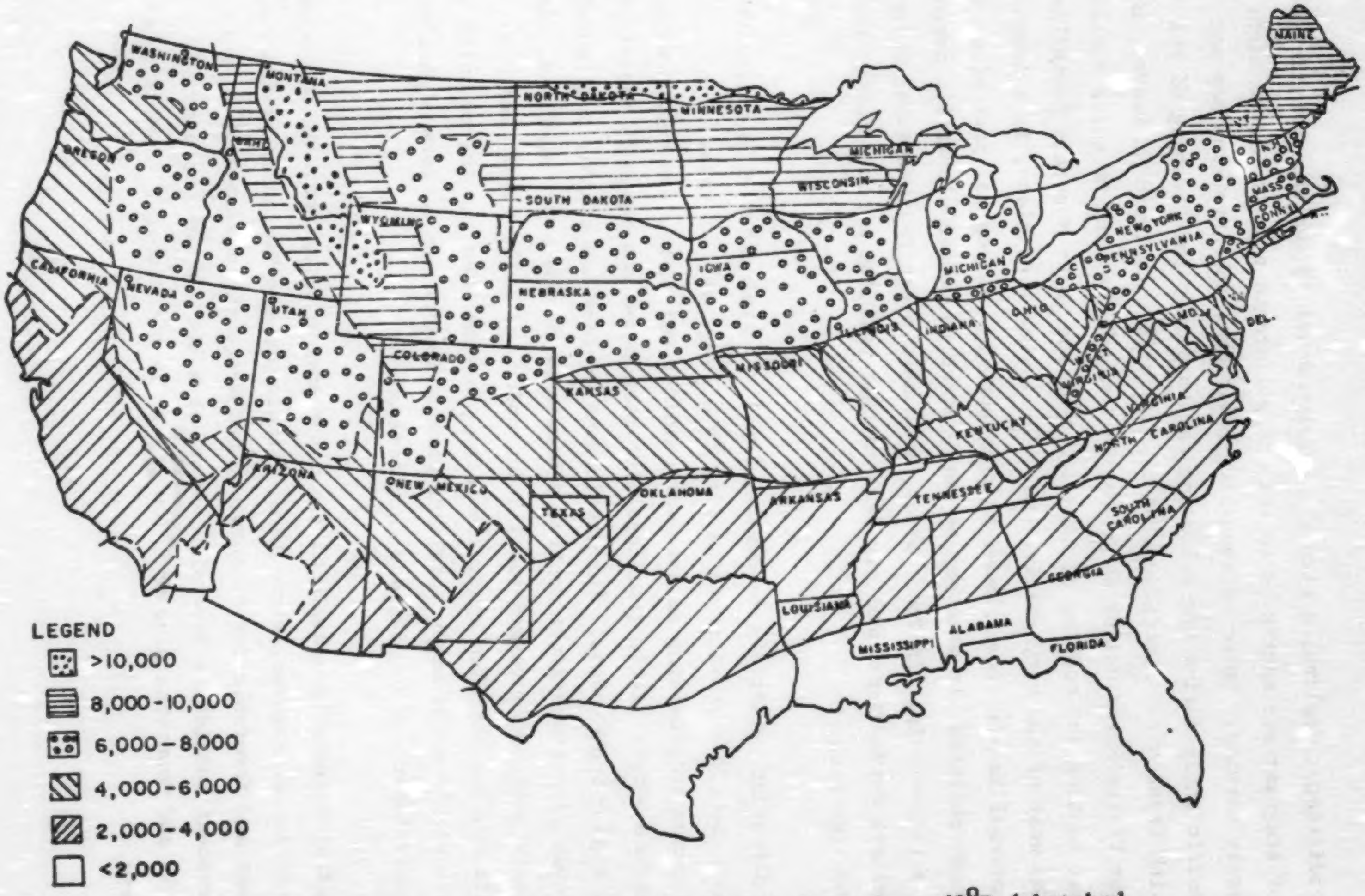
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
MAINE
OREGON
IDAHO
MICHIGAN
WISCONSIN
VT.
N.H.
MASS.
CONN.
SOUTH DAKOTA
WYOMING
NEW YORK
PENNSYLVANIA
CALIFORNIA
NEVADA
UTAH
NEBRASKA
IOWA
MICHIGAN
ILLINOIS
INDIANA
OHIO
MD.
DEL.
COLORADO
MISSOURI
KANSAS
W. VIRGINIA
VIRGINIA
KENTUCKY
NORTH CAROLINA
ARIZONA
NEW MEXICO
OKLAHOMA
ARKANSAS
TENNESSEE
TEXAS
SOUTH CAROLINA
GEORGIA
LOUISIANA
MISSISSIPPI
ALABAMA
FLORIDA
LEGEND
>10,000
8,000-10,000
6,000-8,000
4,000-6,000
2,000-4,000
<2,000

Figure F-27. Average annual heating degree days, base 65°F (sketched from more detailed map in Climatic Atlas of the United States) radiational cooling, a strong inversion develops and the resulting pool of stagnant air continues to collect pollutants throughout the night and early morning. Under unfavorable conditions, the inversion may not lift sufficiently during the following day to permit the flushing of the area with fresh air. A modification of this effect is found in Denver, where the Platte River valley which passes through the city is quite shallow, but heating and cooling of the slopes of the Rocky Mountain foothills to the west of the city result, under light wind conditions, in a diurnal reversal in air flow. Under this meteorological regime, part of an already polluted air mass may be resubjected to Denver's emission during its return trip. In other areas, such as western Pennsylvania, narrow valleys serve to channel air flow so that polluted air repeatedly follows the same path.

A different, generally favorable, local meteorological effect results from the close proximity of a city to a large body of water. In addition to providing an area with minimal emissions, the smooth water surface offers little frictional resistance and consequently contributes to higher wind speeds. The development of land and sea breezes, which result from temperature contrasts between land and water surfaces, also contributes to increased ventilation under initially light wind conditions, but may also aggravate local problems when the inland drift of cool air from the water undercuts warmer onshore air to form a shallow stable layer, as is the case in Cleveland.

Another noteworthy example of the importance of local terrain and meteorology is Los Angeles, where level terrain and the proximity of the sea coast are favorable for dispersion, but where the presence of a semipermanent subsidence inversion serves as a lid and the surrounding hills and mountains slow the flow of air in and out of the Los Angeles Basin.

The preceding examples are given simply to indicate some of the factors controlling local meteorology. Understanding the details of how these factors impact on TSP levels in a particular area requires an intimate knowledge of the emissions and physical nature of the area in question.

SUMMARY AND CONCLUSIONS

We have found no simple meteorological index during these exploratory studies that adequately describes the relative potential for TSP pollution throughout the United States. This is not surprising in view of the complex interrelationships involved. Nonetheless, since the way various meteorological parameters affect TSP levels is known qualitatively, preliminary estimates can be made as to which areas can probably achieve the national standards because of good fortune in their location and which areas will undoubtedly require more extreme control measures if the standards are to be achieved. The use of maps showing the geographical distribution of relevant meteorological parameters, such as those presented in this section, are helpful in gaining general perspective, but final judgment must be based on an intimate knowledge of local meteorology and topography, plus an understanding of the contribution of each emission category to existing TSP levels.

Special studies carried out during the program have provided estimates of the effectiveness of precipitation in reducing TSP concentrations, and indirectly provide an upper bound to the effectiveness of sprinkling or watering programs for widespread TSP control. These studies also provide general guidance for estimating the annual variation in TSP levels to be expected as a result of year-to-year changes in precipitation and degree days.

Some of the principal conclusions drawn during this study about meteorological influences on TSP levels are summarized by topic in the following paragraphs.

Transport and Background Levels

The concentration of particulates in air entering an urban area is the base line value upon which urban emissions build. It varies according to the history of the air mass, and is lowest when the air has had a long water trajectory and highest when it has had a recent trajectory over major industrial areas. Concentrations in coastal regions are affected by the relative frequencies of onshore and offshore winds. Thus levels are low along the west coast and along the southeast coast of Florida where the prevailing winds are onshore, but higher along the eastern seaboard farther north where prevailing winds are from the southwest and west during much of the year. Concentrations are also low in remote, undeveloped areas, and are generally low in rural areas except during periods of soil preparation under dry conditions. An understanding of land use and mean atmospheric circulation patterns, roughly indicated by Figures F-17 and F-18, are useful in obtaining a perspective of regional nonurban levels. Fine particulates, such as secondary particulates formed during atmospheric transport, may remain suspended for several days and thus contribute to TSP levels at distances remote from their primary source.

Effects of Precipitation and Heating Demand

Precipitation is very effective in reducing TSP levels in areas with high concentrations which have resulted from either industrial or fugitive dust sources, and average concentrations decrease steadily with increasing 48-hour precipitation amounts in these areas. The effect of precipitation is greatest on the day it occurs and lasts on the average about 2 days. In our case studies of high-concentration areas, concentrations measured during the last half of a 48-hour period with precipitation $\geq$ 0.25 in. averaged approximately half of concentrations measured during 48-hour periods with negligible precipitation. Concentrations at typical urban sites (excluding clean residential areas) on days with measurable precipitation were about 75 to 85 percent of average values for the site and time of year.

A multiple regression equation, based on year-to-year variations in TSP levels, annual precipitation, and heating degree days in 10 of the study cities indicated that an increase of 1 inch in annual precipitation decreases the mean annual concentration by 0.43 $\mu g/m^3$, and an increase in heating degree days of 1000 increases the mean annual concentration by 2.5 $\mu g/m^3$. The TSP data used in developing the regression equation were drawn from a mix of site types, and from cities where the annual precipitation ranged from a low of 14.0 inches in Denver to a high of 51.3 inches in Chattanooga, and annual heating degree days ranged from 208 in Miami to 6154 in Cleveland. Although conclusions based on this equation must be considered tentative, the relationship provides a ready means for comparing precipitation and heating demand effects throughout the country, For example, the results of applying the equation to the climatological precipitation pattern (Figure F-20) can be displayed as the relative effect of differences in total annual precipitation on the annual TSP level, as has been done in Figure F-28. In this figure a precipitation rate of about 35 inches a year corresponds to the "0" relative effect isopleth. The maximum geographical difference in the annual mean shown by the figure is approximately 35 $\mu g/m^3$ (from -25 to +10 $\mu g/m^3$).

The use of the relationship between heating degree days and TSP level in conjunction with the geographical distribution of degree days shown in Figure F-27 suggests a maximum contribution to the annual mean from space heating of 25 $\mu g/m^3$. The spatial variation in degree days found in the western United States has been drastically smoothed out in Figure F-27, so attention should really be focused on the area east of the Rockies. Here the typical contribution ranges from about 5 $\mu g/m^3$ in the southern tier of states to 22 $\mu g/m^3$ in the most northern states. Again, this is

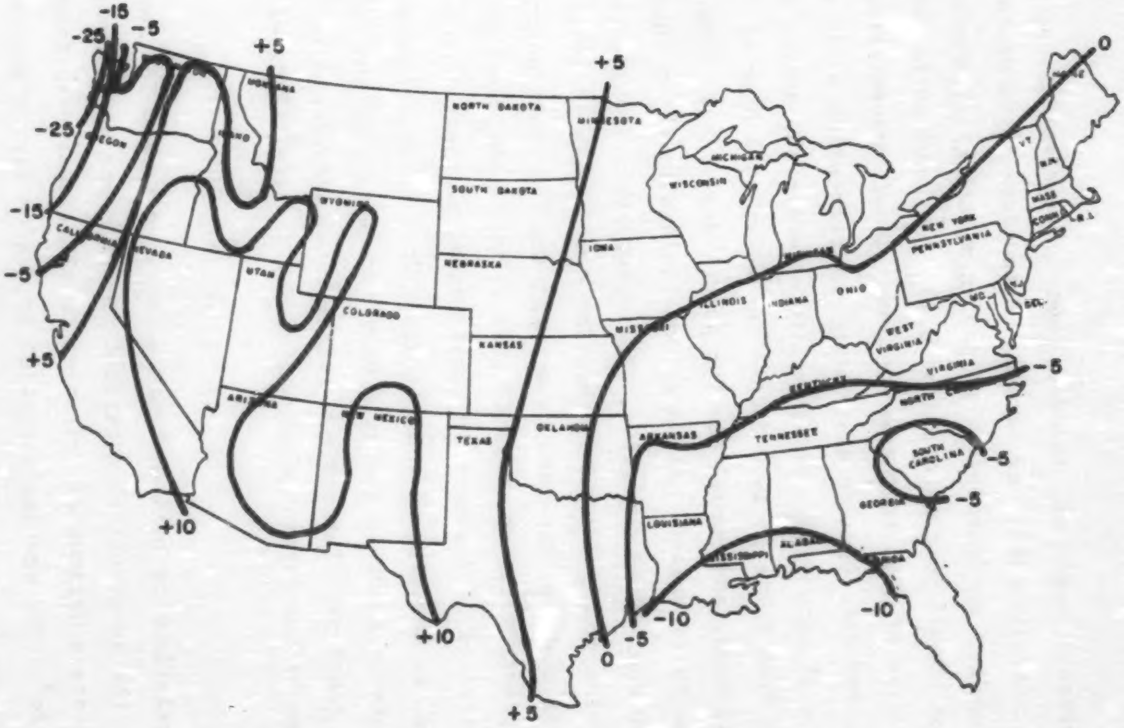
-15
-25
-5
+5
+5
-25
-15
-5
+5
+10
+10
+5
0
-5
-10
-10
-5
-5
-5
0
MONTANA
IDAHO
OREGON
CALIFORNIA
NEVADA
UTAH
ARIZONA
WYOMING
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
MD.
DEL.
VT.
N.H.
MASS.
CONN.
R.I.
MAINE

Figure F-28. Relative effect of annual precipitation on annual TSP level in a hypothetical urban area. (Estimated from regression equation, p. 27

an attempt to generalize the effect of space heating using data from a mix of cities with widely different fuel usage characteristics, and the results therefore are not necessarily appropriate for any specific city.

Effects of Stagnation Periods

We have made no special attempt during these studies to isolate the effects of inversions or stagnation periods on TSP levels. However, several general statements can be made. First, the highest 24-hour concentrations are observed during stagnant conditions since by definition these are periods with very low wind speeds and inversion conditions over at least a 24-hour period. Under these conditions, concentrations typically are about two or two-and-a-half times the average values for the site and time of year. It is under these conditions that the 24-hour standards are most likely to be exceeded. It is not unusual for this increase to be 100 $\mu g/m^3$ or more in the more polluted areas. With this in mind one can use the average annual number of stagnation days from Figure F-24 to approximate the effect of stagnation days on the annual mean. Thus for the area with the maximum number of stagnations as defined and determined by Korshover,[10] stagnations occur on an average of 3.8 percent of the days in a year. If on these days the average concentration is 2.3 times the annual mean, the increase in the annual mean due to the stagnation days is approximately 5 percent.

Effects of Wind Speed

The following conclusions are based principally on 24-hour average TSP concentrations and daily average airport wind speeds in four cities. One of these (Birmingham) is heavily industrialized, two (Chattanooga and Denver) are moderately industrialized, and one (Oklahoma City) is lightly industrialized. Birmingham and Chattanooga have above-average precipitation and low average wind speeds, Denver has little precipitation and below-average wind speeds, and Oklahoma City has nearly average amounts of precipitation and high average wind speeds.

The results of these studies showed that the dilution effect of wind speed was noticeable below speeds of about 10 miles per hour in industrial areas where major contributions were made from point sources. At higher wind speeds and in nonindustrial urban areas, average TSP levels did not appear to be related to wind speed. We were unable to discover to what extent this invariance with wind speed resulted from an interplay between dilution and wind-induced fugitive dust contributions. In this connection, it should be pointed out that the collection efficiency of the hi-vol for the larger particles is believed to decrease with increasing wind speed.

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APPENDIX G

PRELIMINARY ASSESSMENT OF SOURCE CONTRIBUTIONS

ASSESSING SOURCE CONTRIBUTIONS

The development of an appropriate control strategy for improving air quality in a given area involves developing a quantitative knowledge of the contributions of various sources and source categories to the TSP levels in the particular area. Various approaches to assessing these contributions are available; they range from data analysis efforts to extensive particle analytical studies and special field monitoring. Some of the study approaches that are typically applied include:

- Air Quality Data Analysis — Day-of-the-week patterns, seasonal patterns, and time trends and similar paper studies can often be interpreted to provide some information. Wind direction analyses are particularly good in cases of single, directionally clear sources. These simple analyses can permit a good quantitative assessment of nearby source impact if the meteorological circumstances are appropriate.

- Modeling and Other Emission Data Analysis — Emissions data analysis may also be helpful, depending on the data available; in appropriate situations, primarily those dominated by traditional source emissions from well-defined stacks, meteorological dispersion modeling may be particularly useful. However, the lack of reliable inventories of emissions from nontraditional sources and the lack of adequate information on incoming concentrations make most TSP modeling of questionable usefulness.

- Special Analytical Investigations — The potential for identifying particles by various analytical techniques, such as microscopy, wet chemistry, or more elaborate elemental analysis, is great. However, the extrapolation from particle identification to source identification can be intricate and generally requires significant knowledge about the nature of candidate sources. Consequently, specific, well-planned efforts based on some preliminary knowledge are more apt to be productive than general screening studies.

- Special Field Studies — Some short-term field monitoring efforts may more reasonably be the first special studies attempted. The simplest is merely to increase the frequency of hi-vol sampling, to provide more extensive data, or to use additional sites, specifically placed to provide meaningful comparisons or contrasts. More elaborate efforts would involve sampling with special equipment to provide data with a shorter time resolution, directional sampling, particle size analysis, or sampling media more adaptable to chemical elemental or morphological analysis.

PRELIMINARY ASSESSMENT METHOD

In designing a study effort aimed at assessing source contributions, it is helpful to initially develop a preliminary hypothesis concerning the source contributions, to be iteratively modified as further information is developed by whatever study approach is taken. The following is a suggested approach to forming such a preliminary judgment using the results of this study. It is based on systematic comparisons of the TSP levels in the area of concern, suitably adjusted, with the typical values found in similar neighborhoods in the 14 study cities. Following generally the contributions to typical urban TSP as discussed herein, the suggested approach considers in turn the following additive portions of the particulate problem:

- Nonurban particulate levels
- Urban secondary particulate
- Areawide urban activity component
- Industrial or commercial neighborhood influence
- Nearby source influence

Determination of Nonurban Particulate Levels

The first step in identifying the source of urban particulate levels is to establish just how much of the measured levels in fact originate within the urban areas of the AQCR, as opposed to being transported in with incoming air masses. Generally, the careful definition of the urban particulate contribution requires a much more precise definition of the nonurban particulate level than is commonly available or undertaken. Preferably, data on nonurban levels should be available from hi-vol sites established at enough appropriate locations to provide a meaningful average annual value, even weighted by wind prevalence if such sophisitcation is warranted. Unfortunately, such data is rarely available, and it is necessary to use data from existing NASN sites, such as is presented in Figure 4 in Section III. When such data from existing nonurban sites is used, the nature of the site must first be investigated. Many nonurban stations are influenced by nearby low-level fugitive dust sources, as are some urban sites. The purpose of measuring TSP concentrations in nonurban areas, however, is to measure the concentration in the incoming air mass; consequently, such monitoring is one situation in which elevated hi-vol monitoring sites are appropriate.

Determination of Urban Secondary Particulates

The chemical components of the TSP must also be considered in determining the constituents added by the urban area, particularly the major secondary constituents such as sulfates and nitrates. These are known to be both elevated over very large geographical regions, and then elevated additionally within an urban area. The analytical determination of such chemical species in urban samples, such as might be undertaken for strategy development, will require a similar determination concerning the incoming air in order to be most useful. The difference between urban secondary levels and carefully determined nonurban secondary levels can be interpreted as the portion of the urban TSP that will not be susceptible to control techniques directed at particulates per se.

Separation of Urban Activity and Neighborhood Components

The study found that a certain portion of particulate in any urban area is dependent upon the areawide influences from nontraditional sources such as construction, automotive emissions, re-entrained dust, unpaved areas and general urban activity. This component must be separated from neighborhood influences by comparing air quality levels at sites in different neighborhoods. Consequently, it is necessary to classify monitoring sites so that the typical influences associated with each of these sites can be accounted for properly.

Classifying Sites — The neighborhoods in which the existing monitoring sites are located should be carefully studied, and then classified as residential, commercial or industrial to permit comparisons with the study city data. Although most sites are already classified, at least in the SAROAD site description forms, the sampling of sites provided by the cities in this study suggests that such classifications are not commonly done with much precision and should be reviewed.

A variety of definitions of neighborhoods were considered, and the following general distinctions proved to be the most useful categorization for TSP analysis:

- Residential — Those sites that are in completely residential areas, except for a single fire station, school, or other similar building on which the monitor is placed.
- Commercial — The following varieties of neighborhoods are all considered commercial:
  - Light commercial — retail activity, including dense apartment residential, with hotels and motels and other urban activity mixed in.
  - Strip commercial — major traffic artery lined on both sides with commercial activity. Land use may be totally residential behind the commercial establishments.

  - Heavy commercial — this includes both the central business district and light industrial establishments with space heating emissions.

- Industrial — includes only those sites which are in very close proximity (several blocks) to, or actually within, an area of heavy industrial land use.

Classification of Urban Area — The second step of problem identification is classifying the urban area under study with respect to the degree of heavy industrialization, in order to indicate in general the likely dominance of emissions from traditional sources on areawide levels. Since reliable emission inventory data on nontraditional sources do not exist, it is difficult to develop a good overall perspective on the relative balance between traditional and nontraditional sources. Consequently, classification must generally be based only on data concerning traditional sources. The overview of the 14 case study cities does provide some general guidance that is applicable to this judgment. Table G-1 lists the total emissions attributed to traditional sources in the 14 case study cities, not only as total emissions but also on per capita, manufacturing employment, and emission density bases. These figures are not perfectly comparable because of differences in the emission inventories and the differences in the geographic distribution of sources from area to area, but they have been based on comparable areas as best possible.

The primary reason for classifying cities is to direct the general nature of the strategy development effort by obtaining a rough estimate of the traditional source contribution. This determination involves the degree to which an area should approach the development of control strategies for nontraditional sources at present. In those heavily industrialized cities where traditional source emissions still dominate (generally cities with emission densities over 200 to 250 tons per square mile per year), it does not appear possible to use air quality data to quantitatively study or design control strategies for nontraditional sources. It is also likely that any such strategies proposed would be very difficult to support in public. It is therefore recommended that appropriate action in these

Table G-1. TRADITIONAL SOURCE EMISSIONS IN CENTRAL COUNTIES OF 14 STUDY AREAS

Cities	Tons per year	Tons per year per capita x 1,000	Tons per year per square mile[b]	Percent manufacturing employment
Heavily industrialized – Uncontrolled				
Cleveland	210,000	122	335	36.1
Birmingham	110,000	171	488	29.3
St. Louis	190,000	164	411	35.1
Heavily industrialized – Controlled				
Cincinnati	56,100	60.7	135	37.7
Philadelphia	31,600	16.2	245	34.1
Baltimore[a]	23,700	15.5	240	29.3
Moderately industrialized				
Chattanooga	10,300	40.4	88	52.6
Denver	9,700	18.8	60	20.8
Seattle	7,300	6.3	37	26.7
Providence	7,800	13.4	30	44.2
Lightly industrialized				
Washington	5,600	7.4	92	7.2
Oklahoma City	2,600	4.9	2	19.0
Miami	8,000	6.3	30	10.5
San Francisco	4,800	6.7	60	24.4

[a] Includes both Baltimore City and Baltimore County

[b] An area other than central county boundaries was used to calculate emission density in some cases (see Section III).

cases is to concentrate on the control of traditional sources and to gather background information to support nontraditional source control when and if it becomes necessary.

At the other end of the spectrum are those lightly industrialized cities where traditional sources are totally absent or completely controlled (generally those with less than 50 tons per square mile per year). These areas must necessarily plan for or commence nontraditional source control if citywide TSP levels are to be further lowered. It is recommended that such cities minimize the portion of their resources expended on traditional source control, completing the control of existing sources, maintaining compliance, and assuring control of new sources.

Estimation of Undue Influences from Nearby Sources

In order to consider sites as being representative of overall conditions in the particular neighborhoods they represent, the impact of any nearby sources must be accounted for. Typical neighborhood levels may then be compared with the results of the present study. Information and descriptions accumulated during the site visits suggested at first glance that about half of those sites had an effect from a nearby source that appeared to be an undue impact. Upon subsequent comparative analysis of all these sites, however, it became apparent that it was necessary to redefine the subjective definition of "undue local impact" with which we were operating. The aggregate result is that fewer of the sites (about one-tenth) are seen as having "undue" local influences, and more of the observed local influences are incorporated into the neighborhood definitions.

Local impacts from nearby sources must be considered differently in different land use neighborhoods. The following guidelines are recommended for identifying nearby impacts:

> Residential sites: Any noticeable particulate source within about 100 meters, including any small fugitive dust sources within 50 meters, is considered a nearby source.

> **Commercial sites:** Traffic is considered an undue effect only if the traffic source is a major expressway or if the site is very near the street (less than 6 feet high and within 10 feet of a street carrying more than approximately 5,000 cars/day). Building and highway construction are considered local sources if significant projects are located within 300 to 400 meters, or if even very small projects are located within 50 meters.
>
> **Industrial sites:** Nearby sources at industrial sites, especially low-level fugitive dust and reentrainment sources, were so prevalent that no sites in industrial areas are considered to have undue influences, but rather that such influences are routine in industrial neighborhoods.

In planning, the potential range of impact of these nearby sources should be considered so that the areawide influence at the site can be better estimated. Developing carefully defined relationships for making these adjustments was beyond the scope of the present study, but the overall perspective on a large number of sites does permit some rough estimations. Table G-2 lists a variety of situations with undue impact from nearby sources of one type or another, with estimates of the potential range of influence on the annual geometric mean at nearby monitors. Note that the traffic effect is identified only when major expressways are a factor or when the site is very near the street. Other sites, less extremely affected by traffic, are judged not to have a truly undue effect from the streets. The relationship between TSP levels and traffic volumes permitted the development of a rough quantitative relationship (see Appendix E) which could be used to adjust typical commercial sites to a common denominator.

The estimated effects in Table G-2 should be used with considerable judgment and care; they are based on too small a data base to be authoritatively used as firm corrections or adjustments. The best way to use them is iteratively with the development of average neighborhood levels across the city (next step). A site with a suspected undue nearby source influence should first be compared with other sites in similar neighborhoods (e.g., all residential) to establish the excess of the site in question over the typical level at such sites. This comparison can only be done roughly, but if the undue influence is truly significant, it should be apparent. If the excess of the site is roughly consistent with Table G-2, it could be used as supportive evidence for the nature of the influence on that site and a rough approximation of what the air quality would be without that influence.

Table G-2. UNDUE EFFECTS OF NEARBY SOURCES

Effect on annual mean,[a] μg/m³	Nature of source
25-30	Residential neighborhood — small apartment house construction on adjacent property (about 40 m)
15-20	University setting — subway construction along right-of-way 500 to 700 m away
15-20	Three-story high CBD site with intermittent expressway construction within 100 to 200 m
25	Mixed commercial-light industrial with extensive array of local fugitive dust reentrainment sources
20-25	Elevated site within several-block area of ongoing building construction
30-35	Low-level site on traffic island at intersection of major arterial streets
35-40	Low-level site adjacent to elevated expressway and access ramp; in slightly dry city
25	Similar to previous entry in wet city
20-25	Extensive unpaved areas and nearby quarry
30-40	Low-level CBD site subject to extensive ongoing construction activity

[a] These concentrations are estimates based upon averages of levels found at the monitoring sites visited in the 14 study cities; the actual effect at any one monitor may vary widely outside the ranges given.

Comparison of Typical Neighborhood Values to Study Examples

After assessing the various sites used to characterize a type of neighborhood and considering any undue nearby source effects, the next logical step is to group the sites being studied into neighborhood types. This study provides some relatively well-based estimates of typical norms for these neighborhood types, against which the levels at each site in a city can be roughly compared. The final step in this analytical scenario is to make this comparison and interpret the results in the light of knowledge of local sources. This final section presents the TSP levels suggested for comparison and possible reasons why another given city might be higher or lower.

Summary of Typical Source Contributions — The following is a brief description of the methodology used in developing the typical values for each of the components of the urban air at residential, commercial and industrial sites.

Residential Sites — TSP concentrations at residential sites can be thought of as consisting of the following components — nonurban particulate levels, urban area sulfates and nitrates, a general urban activity component, and possibly an industrial influence. The average residential levels in the 14 study cities ranged from 41 to 77 $\mu g/m^3$ after sites with undue influence were removed from the data base. After subtracting nonurban particulate levels and urban sulfate-nitrate excess (as calculated in Section III) the average residential values ranged from 18 to 48 $\mu g/m^3$. After considering this range in conjunction with the nature of the cities, this urban activity component was typically 20 $\mu g/m^3$ in the lightly industrialized cities with the remainder added by industrialization. The variation (18 to 26 $\mu g/m^3$) was roughly correlated with "wet" and "dry" cities respectively, so that precipitation was presumed to account for the range. The industrial influence varied from 0 to 30 $\mu g/m^3$ with the degree of industrialization; typically 5 to 15 $\mu g/m^3$ in moderately industrialized and well controlled heavy industrialized cities and 20 to 30 $\mu g/m^3$ in heavy industrial areas. While other analyses (Section III) suggest that extensive use of fuel oil for domestic space heating can reasonably account for up to 5 $\mu g/m^3$, this could not be confirmed from the data base utilized.

Commercial Sites - A similar analysis of commercial sites yields a commercial urban activity range of 25 to 40 $\mu g/m^3$ (typically about 30 $\mu g/m^3$). It was not apparent that any factor other than increased congestion and traffic accounted for this increase over residential of around 10 $\mu g/m^3$. Industrial contributions at commercial sites were generally 5 to 10 $\mu g/m^3$ higher than at the residential sites, due to closer proximity to the industrial areas.

Industrial Sites — Industrial sites were subjected to a similar analysis. They ranged from 30 to 70 $\mu g/m^3$ above residential values. Those at the lower end of the scale are the cities where hi-vols reflect scattered, isolated industrial activity. Those at the upper end were cities with good representation of sites near major industrial (steel mill) valleys.

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